US Army Corps
of Engineers
Waterways Experiment
Station

AD-A274 912

Technical Report EL-93-26
December 1993

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Containment Area Aquaculture Program

Proceedings of the National Workshop on Containment Area Aquaculture

11-15 November 1991

South Padre Island, Texas

Published by Environmental Laboratory

Prepared for Headquarters, U.S. Army Corps of Engineers

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Aquaculture Program

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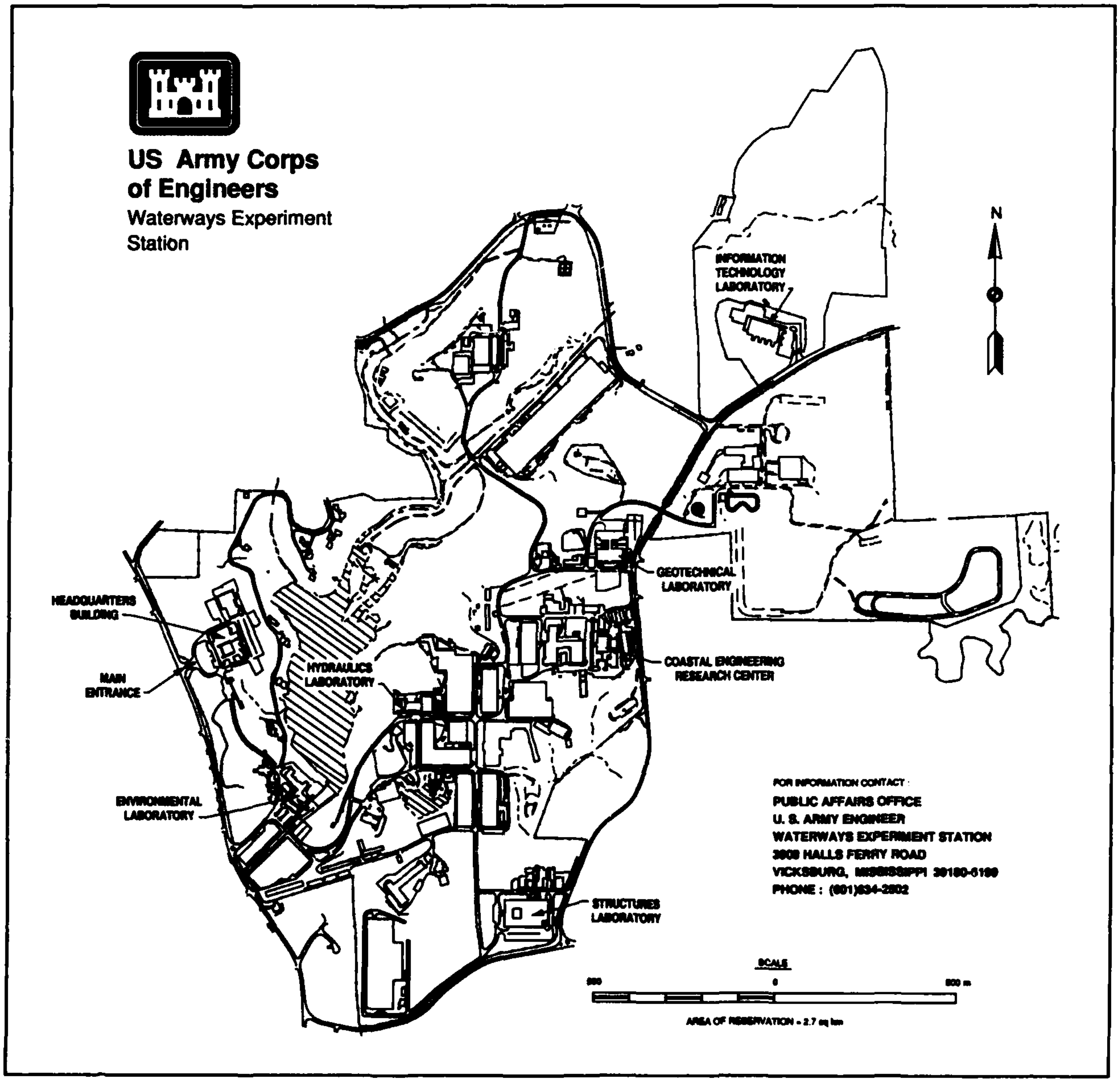
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



Waterways Experiment Station Cataloging-in-Publication Data

National Workshop on Containment Area Aquaculture (1991 : South Padre Island, Texas)

Proceedings of the National Workshop on Containment Area Aquaculture, 11-15 November 1991, South Padre Island, Texas / prepared for U.S. Army Corps of Engineers.

188 p. : ill. ; 28 cm. — (Technical report ; EL-93-26)

Includes bibliographies.

1. Dredging — Environmental aspects — Congresses. 2. Dredging spoil — Environmental aspects — Congresses. 3. Aquacultural engineering — Congresses. 4. Aquaculture — Environmental aspects — Congresses. I. United States. Army. Corps of Engineers. II. U.S. Army Engineer Waterways Experiment Station. III. Containment Area Aquaculture Program. IV. Title. V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; EL-93-26.

TA7 W34 no.EL-93-26

Contents

Preface

High land and construction costs hinder development of pond-based aquaculture in the United States. A partnership with navigation interests may reduce these constraints. The dredged material containment areas (DMCAs) operated by the U.S. Army Corps of Engineers (USACE) are structurally similar to aquaculture ponds and typically are used only once every 3-10 years. With the Corps and navigational interests contributing to dike construction and land acquisition, the costs of aquaculture may be reduced while providing the Corps with the additional disposal areas needed to maintain our nation's waterways. The feasibility of DMCA aquaculture was examined under the Containment Area Aquaculture Program (CAAP), which was sponsored by the Operations, Construction, and Readiness Division, Directorate of Civil Works, Headquarters, U.S. Army Co[illegible]f Engineers, in cooperation with the Const[illegible]on-Operations Division of the US Army Engineers Galveston District.

CAAP was overseen by a field review committee that included Mr. Jesse A. Pfeiffer, Jr., (CERD-C), Mr. John Parez (CECS-OO), Mr. David B. Mathis (CECS-PO), Mr. Glenn Earhart (CENAB-PD-D), Mr. Pat Langan (CESAM-OP-O) , Mr. I. Braxton Kyzer (CESAC-EN-S), Mr. Herbie Maurer (CESWG-CO-M), Mr. Carlos Aguillar (CESWD-CO-DN), and Mr. Tom Patin (CEWES-EP-D). CAAP was managed by personnel from the U.S. Army Engineer Waterways Experiment Station (WES). Mr. Richard E. Coleman was the Program Manager, and the program was conducted under the supervision of Mr. E. Jack Pullen, Chief, Coastal Ecology Branch, and Dr. C. J. Kirby, Chief, Ecological Research Division, and under the general supervision of Dr. John Harrison, Chief, Environmental Laboratory. Program management also was provided by Mr. John Lunz, Dr. Jurij Homziak, and Mr. David Nelson.

The feasibility of DMCA aquaculture was demonstrated in 42- and 47-ha DMCAs near Brownsville, TX. Pumps, filters and drainage structures were added to these DMCAs to accommodate aquaculture operations, and a 1.6-ha nursery pond was constructed. During a three-year period, four crops of penaeid shrimp were raised. Production rates averaged 670 kg/ha of whole shrimp (range: 338 to 1143 kg/ha) with 51 percent survival (range: 23 to 74 percent). Total production for the four crops was 116,088 kg of whole shrimp (71,878 kg tails) and was sold for over $475,000. Publications reviewing the demonstration project from engineering, economic, legal, and environmental perspectives have been prepared.

The culmination of CAAP was the National Workshop on Containment Area Aquaculture, which was held 11-15 November 1991 and provided an opportunity for experts in navigation, dredging, economics, marketing, finance, and aquaculture to meet and discuss the lessons learned from CAAP and to suggest how the information gained could be extended to future applications involving shrimp, fish, molluscs, and plants. The workshop was organized by

Mr. Richard E. Coleman, Mr. Durwood M. Dugger, and Mr. David Nelson with logistic support from Mr. Kevin Reine. Mr. Durwood M. Dugger compiled the proceedings.

Dr. Robert W. Whalin is Director of WES, and COL Bruce K. Howard, EN, is the Commander.

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Introduction

by
LTC James E. Arenz[1]

It is my pleasure to welcome you to beautiful South Padre Island and the National Workshop on Containment Area Aquaculture. This workshop is sponsored by the U.S. Army Corps of Engineers' Headquarters (HQUSACE), the Waterways Experiment Station (WES), and the Galveston District. It is the second such workshop exploring the economical, technical and legal aspects of utilizing upland areas for the combined use of aquaculture and dredged material placement. Through this type of exchange, the Corps can provide information to aquaculturists, port and navigation authorities, government agencies, lending institutions, and private investors on potential rewards and hazards that might accompany the dual use of dredged material upland facilities.

As you may know, the Corps of Engineers (CE) is responsible for maintaining the nation's 25,000 miles of navigable waterways. Part of this obligation requires that the Corps remove approximately 300 million cu yd of sediment from the channels each year. Here in the Galveston District we maintain approximately 1,000 miles of channels and remove approximately 33 million cu yd of sediment annually. The requirement for placement locations for this material is enormous. Approximately 7,000 acres of new upland area is required annually across the nation for the placement of dredged sediments. This requirement puts a huge burden on our local sponsors and the Corps to obtain these areas.

To help alleviate the relocation burden of these vast amounts of dredged material, the Corps is investigating several beneficial uses of dredged material. The beneficial use concept uses the dredged material to environmentally enhance the area in which it is placed. Products of the Corps' beneficial use program include creation of new wetlands, beach nourishment, and construction of oyster, fish and bird habitat. In addition to the aquaculture site which will be discussed at length in this conference, the Galveston District helped provide beach nourishment to South Padre Island by constructing a nearshore berm. A pilot study begun in 1988 showed that sandy dredged material placed offshore would migrate towards the beach and help nourish the beach. On the basis of that study, we placed over 500,000 cu yd of dredged material offshore in 1991 to benefit South Padre Island Beaches. Through this and other innovative uses of dredged material and dual use of upland leveed areas, the Corps, along with local sponsors, is trying to reduce the burden of supplying new disposal areas.

This workshop is the culmination of a 3-yr commercial scale demonstration project which was managed and operated by private shrimp farm management contractors. Several papers and presentations at this workshop will detail the overall results and recommendations of that demonstration. Confined area aquaculture benefits the Corps and local sponsors by making available new upland dredged material containment areas. By providing local land owners an economic incentive to make their lands available without interruption of normal dredge placement operations, the Corps can better fulfill its mission to maintain the nation's navigable waterways. By cooperating with the Corps, the aquaculturist can, at a fraction of the cost of constructing a new site, develop a viable contained aquaculture site. The landowner can then develop the site himself or lease it to an aquaculturist, providing the landowner with a positive economic benefit. The Corps would have a location for the periodic placement of dredged sediments, a viable

[1] U.S. Army Engineer District, Galveston.

aquatic crop would be produced, and the landowner would realize a positive economic benefit; a win, win, win situation.

The Corps is committed to the safety, protection, and enhancement of our environment. Through programs like the Contained Area Aquaculture Program and other beneficial uses of dredged material, the Corps is taking an active roll in the preservation and enhancement of our environment.

Again, welcome to the Galveston District, and I hope you enjoy the South Padre Area.

Containment Area Aquaculture Program: From Concept to Reality

by
Jesse A. Pfeiffer, Jr.[1]

Introduction

I add my welcome to that of Col. Arenz. We are very pleased by the interest in this workshop. I am informed that we have people from private industry, universities, federal, state, and local governments, the Corps of Engineers (CE), and private citizens here today. Your presence is a testament to the nation's interest in aquaculture and productive use of our precious land resources.

My purpose this morning is to develop the background for this national workshop on aquaculture in dredged material containment areas. In doing so, I will emphasize several aspects: the legislative background, the Corps' mission, and the Corps' research and development program. I will discuss how these relate to the Corps' interest in aquaculture and some of the benefits that can be realized from aquaculture in dredged material containment sites.

CE Mission

One of the Corps' vital missions is its legislative mandate to provide navigable waterways in the United States. Historically, this navigation mission entailed both construction and operations activities. As you are all aware, the Corps' mission has been broadened to include regulatory responsibilities. This mandate requires the Corps to dredge in excess of 300 million cu yd of material each year to maintain these waterways. The maintenance of harbors and navigation channels is a necessary and ongoing task. The budget for new work and maintenance exceeds one-half billion dollars annually. Dredging harbors and navigation channels to keep them open produces dredged material which must be placed somewhere. This placement is a constant problem due to the difficulty of acquiring placement sites. The difficulty of finding environmentally compatible open-water disposal sites, prohibitively high costs of upland and coastal areas, and landowner resistance to material placement are also problems in acquiring sites. This is further exacerbated by the fact that channel maintenance often produces little direct benefit for those living adjacent to a navigation channel. An example of this would be an intracoastal waterway in areas where the local population does not directly benefit.

Another hindrance to the acquisition of sites is that dredged material containment areas sometimes are not viewed very favorably. They are viewed essentially as non-productive from both the biological and economic perspectives. Fear of contaminants within these dredged material containment areas elevates concerns, even though studies have shown that more than 95 percent of dredged material is relatively clean and free from contaminants. In general, presence of these sites has been considered incompatible with local ecological and environmental aims.

CE Interest

Next, it is important to note that the Corps does not have a direct interest in aquaculture—our interest stems from our basic mission in navigation. We are primarily interested in relating aquaculture to the Corps' navigation mission. Our aim is to enhance the ability of the Corps to acquire new dredged material placement areas. Dual-purpose use of these new sites for aquaculture and material placement

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[1] U.S. Army Corps of Engineers, Washington, DC.

seems a logical and wise use of our resources. The CE, by virtue of its responsibilities in waterway maintenance, is in a unique position to accommodate aquaculture in its dredged material containment areas since dredged material containment areas must be designated in advance of any maintenance program and the sites often have a long active life—10, 20, even 50 years—making multiple uses of the site possible.

There are other reasons for the Corps' interest in aquaculture. We think that aquaculture is an attractive idea for a variety of reasons. There is a demand for aquaculture products due to declining wild fish stocks, increased costs of U.S. caught and imported fish products, increased demand for seafood, and a dependence on imported seafood to satisfy U.S. demand. The technology for the culture of many species was unavailable historically until recent improvements in culture techniques have made the commercial production of many species possible. This has all happened since we first studied the feasibility of shrimp mariculture in the middle 1970's. The economics of aquaculture, with increasing demand and decreasing wild stocks, has become more and more favorable for many species. During the 1980's Congress recognized this and passed the national Aquaculture Act of 1980 requiring development of a national aquaculture plan.

CAAP Demonstration

In the middle 1970's, little was known about the impacts of dredged material placement. From 1973 to 1978 Congress directed the CE to conduct what was known as the Dredged Material Research Program (DMRP). This research program was broadly based and studied various aspects of dredged material excavation and placement. Its characteristics, impact, and possible productive uses were examined. The DMRP provided a foundation for understanding the effects of dredged material placement. Although the DMRP answered many critical questions, it raised many more. As an example, one area of research was a feasibility study of shrimp aquaculture conducted at Freeport, TX. Although it established the feasibility of such a project, it left many unanswered questions, questions that the Containment Area Aquaculture Program (CAAP) demonstration was designed to explore.

The CAAP field demonstration was conducted from late 1986 through the summer of 1989. The approach was to apply the knowledge developed during the DMRP, along with technology developed in the aquaculture industry, to conduct a commercial-scale aquaculture operation. The major goal was to demonstrate the technical and economic viability of aquaculture at an active dredged material containment area, as well as the compatibility of aquaculture operations with the placement of dredged material. A second main goal was to communicate the results of the demonstration by means of reports, extension documents, and workshops to as wide an audience as possible. These goals were achieved, and the results will be presented to you during the presentations in this workshop.

Although penaeid (marine) shrimp were used in the demonstration, we have asked experts to discuss the potential for other aquaculture species in these areas and appreciate their willingness to share their knowledge.

Productive use is something in which we are interested. It fits the current administration's outlook on productive returns. Although the primary role of dredged material containment areas is to contain dredged material, it is a passive role. If these sites could be used for productive multiple use, it would be good for everyone.

Benefits of the CAAP

We think benefits can be realized by all the involved parties if this concept is expanded and applied. First, there will be benefits to the public. It could provide local employment and an economic stimulus. It could increase the value of the land where the site is located. For the CE, the favorable and economically attractive multiple uses of a containment site could enhance the ability of the

Corps' to acquire new acreage for dredged material placement and to avoid the unpopular process of condemnation. An aquaculture option would provide the landowner, often a local governmental body or dredging sponsor, with reasonable compensation for use of the disposal site. It could make a difference to a landowner or to a local government if some productive use could be derived from a site instead of having it lie unproductive for years. For prospective aquaculturists, it affords the opportunity to access prime sites and potentially reduce some of the up-front costs associated with land acquisition and facilities construction. The Corps would also gain some positive publicity, and it would promote cooperation between governmental agencies involved in aquaculture.

The CAAP was designed to address questions with regard to the full potential of aquaculture in dredged material containment areas: engineering, economic, pond management, biological, contaminant, and legal. This conference was organized to avail to you CAAP results and to promote this productive use of dredged material containment areas. The workshop program format has been designed to expand on the technical, business, and public opportunities offered that may be available, and I would like to encourage a lively participation and interchange of information and ideas. I firmly believe the concept is a win-win situation for all.

Aquaculture in the United States

by
Robert R. Stickney[1]

Introduction

Aquaculture, the rearing of aquatic organisms under controlled or semi-controlled conditions, began in the nineteenth century when the U.S. federal government and the various states began producing aquatic organisms for stocking into public waters. One needs only look at some of the reports issued during that period, for example that of Brice (1898), to see that literally hundreds of millions of fish and shellfish were being produced. Those animals were usually stocked immediately because culturists at the time had no means of rearing them in captivity. The contribution of the released larvae to the fisheries must be considered as extremely limited.

Commercially, aquarium and bait fishes have also been of historical importance as aquaculture products in the United States. Some 35 years ago, Dobie et al. (1956) discussed 20 species of fishes that had been commercially produced for bait. Since then, a large number of ornamental fish farms have gone into production. The bulk of the tropical fish farms with outdoor ponds are located in Florida, with goldfish farms and some facilities involved in tropical fish production being scattered about the nation.

Aquarium fishes, baitfish, and the production of sport and commercial fish in governmental hatcheries continue to be important sources of aquacultured animals in the United States. Commercial aquaculture aimed at producing food organisms did become a very visible industry in the United States until the 1960s. Since that time, three groups of animals have become dominant: catfish, trout, and crayfish. Other animals that have been cultured for human consumption include marine and freshwater shrimp, oysters, clams, salmon, buffalo, red drum, sturgeon, and tilapia. Among those, salmon and oysters lead in terms of total production and value. Research and, in some cases, a limited amount of commercial culture has also been conducted with a variety of other species ranging from lobsters to dolphin.

Culture intensity (Figure 1) is highly variable, both within and between species. The most extensive (least intensive) type of aquaculture system can be characterized as a farm pond or small lake stocked for subsistence harvest or an oyster bed where management might be as simple as the annual deposition of old shells on the grounds to provide substrate for the settlement of spat. The most intensive form of aquaculture involves closed recirculating water systems which feature water treatment and reuse and should be equipped with a high degree of redundancy with respect to all mechanical parts. Some species have been raised in an array of culture systems that virtually span the breadth of the intensity scale. Others have only been reared within a narrow portion of the continuum.

As recently reviewed (Anonymous 1990), aquaculture production in the United States was 402,757 tons in 1988 with a value of $608,858,000. The projection for 1990 was 503,446 tons with an estimated value of $755,163,000, indicating that the industry is still in a growth phase. Total world tonnage from aquaculture was placed at 13,708,963 in 1988 (Anonymous 1990), which would give the United States slightly less than 3 percent of the total.

The bulk of the channel catfish produced in the United States are grown in Mississippi.

[1] University of Washington, Seattle, WA.

High Intensity

Type of System	Production (kg/ha/yr)
Closed Recirculating System	1,000,000
Partial Recirculating System	1,000,000
Linear Raceways	
Circular Raceways	
Cages in Flowing Water	100,000 to 1,000,000
Cages in Static Water	10,000 to 100,000
Ponds with Complete Feed and Limited Water Exchange	4,000 to 10,000
Static Ponds with Complete Feed	2,000 to 4,000
Pond with Supplemnental Feed or Fertilized	1,000
Pond Receiving No Feed	500

Low Intensity

Production Figures are Relative and are Presented for Comparative Purposes

Figure 1. Types of aquaculture systems

Total estimated pond area devoted to catfish culture in 1990 was about 71,000 ha of which 59 percent were in Mississippi, 12 percent in Arkansas, 11 percent in Alabama, and 7 percent in Louisiana (Anonymous 1990). Several other states, mostly in the south, also produce catefish. In the west, only California has significant production. In 1991 there were 475 catfish farms in Mississippi, up by 50 in 1990 (Gair 1991).

While trout are cultured by state and federal agencies for recreational stocking in most states, the culture of rainbow trout for the retail market is dominated by Idaho where several large trout farms in the Hagerman Valley near Twin Falls control most of the industry. An enormous supply of groundwater outwelling into the Snake River in the Thousand Springs area provides excellent water quality for the trout raceways. Fish, both fresh and frozen, are processed locally and shipped throughout the country.

Crayfish are harvested from nature, primarily in Louisiana, and are farmed in ponds using low intensity technology. Trapping is still the method of harvest used both by farmers and commercial fishermen. Crayfish farming has developed rapidly in Texas within the decade, and there is a limited amount of production in other states. Because of their life cycle, crayfish are a seasonal product. When the commercial harvest is large, the price can drop to the point that culture of the animals becomes uneconomical. In years when natural production is low, crayfish farmers can make reasonable profits.

Production of crayfish is in shallow ponds, often converted rice fields. If a farmer could predict whether the wild catch in a given year

was going to be large or small, a decision could be made as to whether crayfish or some other crop would provide the better income from the land. At this point, it is not possible to make that prediction, though some farmers rotate their land from crayfish to rice and other crops.

The potential for the U.S. salmon industry in the Pacific Northwest, including Alaska, and on the coast of New England, particularly Maine, is great, but various constraints have inhibited development of the industry. Both Atlantic and Pacific salmon have been successfully reared in net-pens placed within coastal bays and sounds. Salmon can also be grown entirely in freshwater as demonstrated by the large recreational fishery which has been created in the Great Lakes for both coho and chinook salmon introduced from the west coast.

Diseases and degraded water quality in Atlantic and Gulf of Mexico coastal waters have destroyed the oyster fisheries in such areas as Chesapeake Bay and Apalachicola Bay. Actions are being taken to limit the impacts of man on those environments and may restore many perturbed environments, but the disease problems, which have been the subject of research for many years, continue to plague the industry. Pacific oysters, introduced to Washington and Oregon from Japan early in the present century, have become the mainstay of the cultured oyster industry. For many years, spat were introduced each year from Japan, but within the past few years, hatcheries in Washington have been able to sufficiently produce millions of oyster spat which are planted on well-managed beds. Many of the Washington oysters are shipped to the east coast and other regions where demand is high, but supplies have become depleted.

Constraints

Constraints to development of aquaculture are primarily physical, environmental, and political. Physical constraints relate to the availability of land with proper water holding soils (in instances where ponds are to be constructed) and with an adequate supply of water with the proper quality for use in aquaculture. Those constraints can be ameliorated to some extent by going to more intensive systems, like raceways and tanks, and by recirculating most or all of the water that is used. As intensity of culture increases, so does the cost of constructing and operating the facilities, and in many instances a fiscal constraint develops because costs of production exceed the value of the crop produced.

The political and environmental constraints are largely associated with aquaculture activities that take place in the commons, though all aquaculture facilities in the United States are constrained to properly dispose of or treat their effluents when the discharged water empties into the public waters of the nation. Growth of the raceway trout industry in Idaho has led to increasing pressure against expansion as the introduction to receiving waters of fish wastes is viewed as a negative impact of the trout farms on natural habitats in at least some circles. The farmers are responding by constructing waste treatment facilities through which effluent water is passed. There has been less concern about the effluent from catfish farms where the farming of fish in rural areas where the industry is centered is seen as just another agricultural pursuit. Since agriculture is the mainstay of the economy in those regions, it is favorably viewed. Discharge water from catfish farms may, in some cases, actually have better quality than that in the receiving streams, though monitoring and treatment may be required to ensure the health of receiving waters.

The major controversy surrounding aquaculture in the United States has been in association with activities in the coastal zone, particularly if those activities involve the use of structures which are visible to other users. While there has been some controversy surrounding the culture of oysters, for example, the furor is not too great when bottom culture, a relatively unobstrusive technique, is practiced. However, as soon as an aquaculturist seeks a permit for raft or string culture of oysters or other molluscs, the opposition becomes mobilized.

The controversy has been particularly great with respect to the culture of salmon in net-pens in Puget Sound, Washington. Aquaculture of salmon has become so controversial in Alaska that net-pen salmon culture is against the law in that state. Recently, there has been interest in developing legislation that would prohibit not-for-profit ocean ranching of salmon as well.

Opposition has generally been from two groups. Commercial fishermen see salmon net-pen culture as a threat to their ability to remain in business, though the United States imports a great deal more salmon than is produced by domestic aquaculturists. Norway, Chile, and British Columbia are much larger producers of cultured salmon, with much of their produce being targeted at United States markets. It is now possible to find fresh salmon in the super markets of almost every major city and in many smaller ones throughout the country.

In some nations, such as Norway, salmon fishermen are also salmon aquaculturists. That course of action has been suggested for U.S. fishermen (Stickney 1988), but has not been adopted. While some fishermen have expressed an interest in also raising salmon, peer pressure against branching out into aquaculture has been very effective.

The second major opposition group are upland and waterfront land owners who are opposed to having their views impacted by the presence of net-pens. That opposition has been most strongly expressed in Maine and Washington. In Washington, the state commissioned an environmental impact statement (Washington Department of Fisheries 1990) which addressed the concerns that had been voiced by opponents. As reviewed by Stickney (1990), the concerns revolved around so-called visual pollution, environmental impacts, and interference with recreation and commerce. The courts have indicated that adjacent and upland landowners are not guaranteed that their view will not change over time, and judges have shown little sympathy for the opponents' claims that net-pens are disruptive to the aesthetics associated with a particular piece of property. Therefore, a series of additional concerns have been developed. They include:

- Impacts of net-pen salmon culture on water quality
- Impacts on the benthos community under the net-pens
- Impacts of antibiotics in fish feeds on indigenous bacterial flora
- Transmission of diseases from cultured salmon to wild fish
- Mixing and interbreeding of escapees from net-pens with wild salmon
- Impairment of navigation
- Interference with commercial fishing activities
- Exposure of humans to pathogens carried by cultured fish
- Interference with recreation
- Excessive noise
- Noxious odors

The Environmental Impact Statement (EIS) deals with each of these issues. Some are dismissed as being perceived rather than real problems, and recommendations to avoid or mitigate against the others are provided. The EIS concluded that net-pen aquaculture can be an appropriate use of coastal environments if sites are carefully selected and managed. The convoluted permitting process which exists in Washington relative to establishing a net-pen facility continues to require an inordinate amount of time and expense and has led to a virtual cessation in the generation of permit requests. Currently, there are about one dozen salmon net-pen facilities in the state, and that number may not rise in the future.

While net-pen's culture is not a form that will be applied to containment aquaculture sites, its cousin, cage culture could be practiced

in those environments, particularly in instances where the containment sites are large and sufficiently deep. Use of upland facilities, of which containment aquaculture sites would be one example, have generally fared better than marine sites relative to the development of a vocal opposition. Some upland permit seekers have been blocked by organized opposition, however. As wetland protection becomes increasingly important in the United States, sites that have been set aside for other uses, such as dredge material containment sites (which have often been constructed over wetlands), provide aquaculturists with what could become an increasingly attractive alternative.

The ease with which permits for aquaculture can be obtained varies considerably from state to state and even from one part of a state to another. The difficulty involved in establishing fish culture in the Puget Sound region of Washington would not apply to trout farming in the eastern portion of the state, though the water resource is tightly controlled in areas where irrigation is practiced, and it may not be possible to obtain water year round in those areas. However, if suitable conditions for establishment of an aquaculture facility could be found, the likelihood that there would be any organized opposition is not great. Included among the reasons for the differences are the density of the human population in the two parts of the state and the sociological values that prevail.

In western Washington, the density of people is very high, and most of the people are located in urban areas adjacent to the waters of Lake Washington and Puget Sound; the waters are seen as a community resource; and there is a growing feeling within the public, reinforced almost daily by the media, that the aquatic environments are being irreparably damaged by man's activities in the region. Aquaculture came on the scene very late in the development of the region, arriving just about the time that further development was being questioned and even curtailed. On the eastern side of the state, the population density is low, and the people are primarily involved in agriculture. Aquaculture is seen as a potential extension of traditional agricultural practices, produces a crop, and can provide economic benefit to communities in addition to individual farmers. Thus, the social psychology is quite different.

Situations analogous to that which exist in Washington can be expected to occur in most other coastal states. The details may vary, but the general issues will apply. In most states which have well-developed aquaculture industries, the farming of aquatic species is practiced in traditional agricultural regions. That may change in the future as interest in mariculture (the farming of marine organisms) continues to develop in the coastal regions of our country.

Although there are cases where local residents fearful of a decline in recreational fishing due to water quality degradation in the river have objected to aquaculture, most rural communities not only tolerate, but are supportive of fish farming activities. In some coastal states, or parts thereof, aquaculture may not be seen as an inappropriate use of the marine environment, but competing users can drive the price of land up to the point that viable aquaculture ventures cannot be developed. Condominiums, resort hotels, housing developments, marinas, and industrial plants are common competitors for land that might otherwise be suitable for aquaculture enterprises. The potential profits from aquaculture do not justify the purchase of land, the price of which has been inflated by those interested in other uses. On the other hand, land that has little or no value by other user groups may also be unsuitable for aquaculture because of physical constraints such as a good supply of freshwater for dilution of the saltwater or soils that do not hold water. Proximity to markets is another consideration in site selection.

Land can also be a constraint in non-coastal regions where soils do not properly hold water. While it is possible to line ponds or rear fish in concrete raceways or indoor tanks, the costs of such culture chambers may be prohibitive.

Inland, water is probably the major limiting factor. The catfish farming industry of the United States was centered in Arkansas until the water table in that state began to drop precipitously. During the 1970s, catfish farmers discovered the seemingly inexhaustible ground-water resource of the delta region of Mississippi, and that state soon became the number one catfish growing state in the nation. In recent years, the incredible demand for water in the Mississippi Delta has demonstrated that the supply is actually finite, leading to re-evaluation of how much expansion of the Mississippi industry will be possible under present production strategies.

Many aquaculturists see feed ingredients, in particular animal protein, as being a pending and potentially significant constraint to future development of the industry. Aquatic animals, with few exceptions, require some animal protein in their diets to meet the requirement for essential amino acids, which serve as the building blocks of protein. Much of that animal protein comes from fish meal. Demands for fish meal by producers of livestock and poultry, coupled with the growth of demand for fish meal from aquaculturists, may exceed the supply in the future. Problems with fish meal supply resulting from El Niño events off Peru and Chile in the past have led to precipitous increases in the price of fish meal during certain years. Also of importance with respect to the future availability of fish meal is the fact that with developing technology it is becoming possible to turn fish that were once used for fish meal into surimi analog products such as artificial crab legs and shrimp. Fish which were only worth a few cents per kilogram to the commercial fishermen when they were to be rendered into fish meal become much more valuable when processed into surimi. Aquaculture nutritionists are actively seeking alternatives to fish meal in aquatic animal diets, but other suitable animal protein sources such as meat and bone meal and poultry byproduct meal are also available in only limited supply.

Role of Containment Aquaculture

The use of dredged material containment sites as aquaculture ponds makes a considerable amount of sense from many points of view. In the first place, finding a potentially profitable use for containment sites can be done with appropriate advance planning and modifications that may be as simple as adding drains and inflow pipelines. Dredged material containment ponds may be viewed as unattractive, particularly if they are not well landscaped and maintained, while aquaculture ponds are not aesthetically displeasing if the banks are planted with grass and are mowed as necessary. Containment ponds are often located in areas where they might otherwise be competing land use conflicts and where aquaculture would not be economically feasible. By making such ponds available for fish culture, not only can aesthetics be improved, but some economic benefit can be obtained from what would otherwise be unproductive land.

Aquaculture species require the best water quality that can be provided. Contaminated soils must be avoided as toxicants that leach from such soils will enter the aquatic animals and be directly toxic or make the animals unfit for human consumption. Thus, care must be taken to ensure that the use of containment ponds for aquaculture is restricted to those sites into which only uncontaminated sediments are deposited. The water used to fill and maintain the ponds must also be of good quality as is true for any aquaculture operation.

The use of containment sites for aquaculture appears to make very good sense. Given good quality water, uncontaminated sediments, and an appropriately constructed containment pond, there is no reason to believe that an aquaculture venture would be any less successful in such an environment than in ponds constructed only for aquaculture.

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Economics of CAAP

by
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Abstract

The U.S. share of world farmed production has recently slipped as a result of record world farmed shrimp production of near 770 million lb (tail weight) in 1989. Thus, there may be U.S. growth in terms of companies and production, but foreign growth appears to overshadow domestic efforts. This is an economic reminder that success and growth hinge on comparative economic forces among countries.

The issue of comparative economic advantage for U.S. shrimp aquaculture focuses on the availability of sites and construction costs. Shrimp aquaculture that is pond oriented will never be a large industry in the United States without the availability of more sites. Construction on the sites that are technically and politically feasible must be achieved economically. Regulations and permits often determine the size, shape, arrangement, and construction procedures for ponds, and thus ingrain higher costs.

Maintenance dredging in waterways often requires long-range planning in order to ensure the availability of sites to deposit dredged material. The Containment Area Aquaculture Program (CAAP) will reduce the difficulty of obtaining deposition sites by offering landowners an inducement to cooperate with local Corps of Engineers districts. This inducement is twofold: (1) landowners interested in the program will benefit by the cost savings associated with pond construction, and (2) landowners will receive technical aquaculture assistance through information transfer from the CAAP demonstration project in Brownsville, Texas.

Containment area aquaculture will have positive impacts other than those which directly affect the landowner and the district. An aquaculture operation will provide employment for the local workforce, will stimulate the local economy, and may improve wildlife habitat by the creation of protected waterbodies. The program represents resourceful land use and will foster a mutually beneficial partnership between the Corps of Engineers and the private sector.

This report provides a preliminary economic and marketing analysis of the CAAP demonstration project in Brownsville, Texas. It is preliminary in that sales data from October, 1989 harvest were not available at the time the report was prepared. In the future, this analysis will be updated with those data and provided in a more comprehensive report dealing with the economics and marketing of dredged material containment area (DMCA) aquaculture.

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Hard Clam and Oyster Aquaculture in the Southeastern United States: An Economic Overview of Current Technologies and Implications for Containment Area Applications

by
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Introduction

Hard clam (*Mercenaria mercenaria*) and American oyster (*Crassostrea virginica*) aquaculture has received increased attention by potential commercial investors in recent years. This is particularly true for specific locations within the southeastern region of the United States, where habitat and environmental conditions are favorable for commercial production. A number of recent key innovations and methodological improvements have enhanced the economic feasibility of culturing hard clams and oysters on a commercial scale. As a result, the number of investors and production volumes in bivalve aquaculture within the southeastern U.S. region has increased.

Although recent technological advances have increased the rate of development in the bivalve culture industry in the region, the potential exists for the future availability of suitable public submerged lands for lease by culture facilities to be reduced. Such a development would likely dampen the current growth rate of these industries. Suitable sites may become more limited in number as local water quality is reduced and more restrictive assessments of water quality are imposed by state and federal agencies. This trend has, in fact, already begun. For example, the number of approved shellfish harvesting areas in Florida was reduced by 60 percent from 1980 to 1990 (Florida Department of Natural Resources 1991). The number of conditionally approved and prohibited shellfish harvesting areas in Florida increased by 2.5 fold and 30 percent, respectively, over the same period. In addition to water quality concerns due to urban runoff and other non-point pollution sources, potential limitations to the availability of leasable bottom also include aesthetics, navigation conflicts, theft/vandalism, and other factors associated with a rapidly urbanizing coastal population.

These potential constraints may warrant current and prospective bivalve culturists to augment or replace production practices on public leases with the use of private lands for siting commercial hard clam and oyster culture operations. One possibility is the construction and utilization of dredged material containment area (DMCA) ponds on suitable coastal private property.

This paper will address the economic implications of siting existing hard clam and oyster culture technologies in containment area ponds. A brief overview of existing production methods will be presented. The costs and revenues of the various production systems will be detailed on a pro-forma basis. Then, potential consequences of locating the systems in a containment area pond environment will be suggested.

Hard Clam Culture

Industry history

Commercial interest in hard clam aquaculture dates back to the early 1900's. Initial success in larval hard clam culture was achieved in the 1920's (Loosanof and Davis

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1963a and 1963b). By the 1950's, the methods for culturing larval and juvenile hard clam were well understood. The first commercial hatchery in North America began operations in 1956 in Virginia. Commercial success for hard clam aquaculture, however, was further dependent on development of technically feasible nursery and field growout methods. Not until the 1980's were innovations in nursery and growout methods standardized to the extent that hard clam aquaculture became attractive to increasing numbers of commercial investor in the southeastern U.S. region. As a result, hard clam aquaculture production volumes increased steadily during the 1980's. Aquaculture's share of the total U.S. supply of hard clams (i.e., wildstock plus aquacultural production) increased from 5.8 percent in 1981 to 30.1 percent in 1989. The volume of cultured hard clams was expected to exceed that for wildstock hard clams in Florida for the first time in 1990 (Vaughan, D. E., personal communication).

Production methods

The hard clam aquaculture production process employed by culturists in the southeastern United States consists of hatchery, nursery, and growout phases. Each phase utilizes distinct technologies in order to produce clams of a specific size. These methods will be briefly discussed below. In addition, specific recent technological improvements for each phase will be mentioned.

Hatchery. The hatchery phase involves the spawning of broodstock clams and rearing larval clams up to 1 mm juveniles. This process involves alternating exposures of adult conditioned clams to chilled and warmed sea water. Following several exposure cycles, the clams will spawn. The fertilized eggs are placed in growing tanks where they develop into larvae. The larvae will "set" (i.e., metamorphose from larval to adult form) after 7 to 14 days. The set may be left in the growing tanks and fed cultured algae, but are preferably placed in either upweller or downweller units, through which algae-enriched water is circulated on a continuous basis. The algae are typically mass cultured from unialgal flask cultures of preferred, but possibly non-endogenous, species in a controlled algal-culture system. This method, where controlled algal culture is utilized, is referred to as the Milford method (Castagna and Kraeuter 1981). Depending on local water quality and temperature, the entire hatchery process can require 30 to 50 days to go from spawning to 1-mm seed clams ready for placement into a nursery system.

The refinement of hatchery technology, including upweller/downweller design and algae culture methods (i.e., the Milford method), has had a dramatic impact on seed availability. As recently as the mid-1980's, no commercial hatchery operations existed in the Southeast, with the exception of Virginia. This presented a virtually insurmountable constraint to the further development of nursery and growout operations in the region, which effectively stifled further industry development and aquacultural shellstock market growth. The refinement of algae culture techniques which focused on non-endogenous algae species, specifically the standardization of the Milford method, led to significant increases in the hatchery survival rates. These improvements meant that consistent algae supplies, the key to successful post-set rearing, were no longer dependent on the inconsistent availability of indigenous algae species. In addition, advances in genetic manipulation have allowed culturists to reduce growth rate variability in a given cohort of seed clams and better match seed clams to the vagaries of local environmental conditions.

Nursery. The nursery is a crucial link in the hatchery to growout culture process. Placing hatchery reared seed clams, which emerge from a closely monitored and controlled environment, directly into the field growout environment would yield an unacceptably high level of mortality. The nursery provides a semi-controlled, intermediate phase in which the hatchery reared seed clams are nurtured to a size less vulnerable to the stress imposed when placed in the final, field growout phase. From an economic perspective, growing seed to the size required for the growout phase

within an investment intensive hatchery environment would likely not be cost effective. The length of time required by a nursery to produce a 7- to 15-mm seed clam, which is the size typically required by growout operations, will depend largely on water quality and temperature. Nursery operations typically do not introduce cultured algae into the ambient seawater, but rather rely on existing algal concentrations. For the southeastern region, the nursery process can require from three to six months.

Nursery methods can either be land-based or actually located in the water. Three basic methods are currently utilized by industry (Manzi and Castagna 1989). These include the land-based upflow, land-based raceway, and field tray systems. The land-based upflow system utilizes ambient seawater, which is pumped to reservoir tanks and upflow cylinders which bathe the seed clams with a continuous, vertical flow. Several upright, circular upflow units (open-ended, cylindrical tubes of desired diameter) may share a common reservoir of water. The flow of seawater can either be active (water is forced up through the seed clams) or passive (water is pulled up through the seed clams at a lower relative velocity).

The land-based raceway systems include long, narrow, shallow, wooden trays which have been sealed with a protective lining, such as epoxy, resin, or plastic. The raceway system may incorporate several levels of trays. A thin layer of sand covers the bottom of each tray, over which the seed clams are distributed. Raw, ambient seawater is pumped into one end of a tray at an appropriate rate so as to establish a shallow, horizontal flow across the seed clams.

The field-based system involves placing seed clams directly from the hatchery into the submerged open-water, bottom setting. However, design and maintenance characteristics of field-based nurseries require that a seed clam no smaller than 3 to 4 mm be utilized. Also, the larger seed clams will be more resilient to the stress imposed by the natural environment. Because field-based nurseries can be employed in both subtidal and intertidal environments, the systems assume a variety of forms. Traditional designs utilize trays of cages made of wood, which contain a layer of gravel or sand, and have a protective plastic mesh cover to discourage predators. More recent innovations include floating wooden trays and systems of bags held together in long "belts." The latter uses a series of mesh bags held together with small diameter polyvinyl choride (PVC) piping. Such designs significantly reduce maintenance and labor expenses. Field-based nurseries are placed in protected shallow water areas, where wave action, siltation, and the threat of poaching can be minimized. More recently, floating pen systems have been developed, although currently these are not in widespread commercial use. These floating systems are composed of wooden or PVC pipe frames which hold pens of small mesh sides and bottoms. Water movement is enhanced and accomplished with either airlift stones or fan-style pumps. Since the units are floating, the water needs only be moved a few inches vertically to achieve the necessary flow, as opposed to being lifted several feet to supply land-based systems. The floating pens can be covered to reduce biofouling.

One of the major "weak links" in the entire hard clam culture process in the past was the lack of sufficient quantities of appropriately sized seed clams. Planting seed too small to withstand the stress of an open water growout environment resulted in unacceptable mortality rates. Recent improvements in nursery methods have increased the seed size available to growout operations and thereby increased survival to final harvest. In addition, the range of culture methods available to nursery operations has increased significantly. This increased selection of methods allows the prospective nursery investor a greater range of potential sites, as well as the ability to better take advantage of the environmental and physical characteristics of a specific location.

Growout. As with nursery systems, a diverse variety of growout systems exist (Adams et al. 1991). Although land-based growout methods have been developed, the current and

more widely accepted technology is better suited for field-based growout systems. The specific design of these field-based systems varies considerably, but most growout operations use some form of pen, tray, or net. Each of these alternative methods is to a degree better suited for certain types of habitat, which can vary considerably within the southeastern U.S. region (i.e. intertidal vs. subtidal, sand vs. mud). Although hard clam size class designations recognized by the local market may vary from state to state, the "littleneck" (i.e., approximately 45- to 50-mm longest shell dimension) draws the highest per clam price. Therefore, growout operations will typically attempt to target this size class. The length of growout time will largely depend on water quality and temperature. The length of time necessary to reach a 45- to 50-mm size from 7- to 15-mm nursery clams may require 18 to 36 months.

A variety of growout methods are currently in use. The pen, tray, and bottom net will be discussed. Pens are shallow cage-like containers which are composed of a rigid frame with a plastic mesh enclosing the sides and top. The seed clams are distributed evenly over the bottom, with the pen placed on top of the seeded substrate. The mesh enclosure allows water to move through the structure and over the clams, yet restricts predator access. Siltation is allowed to build up within the pen, yet not to a depth which would suffocate the clams. The size of the pen can vary. Often pens are located in an intertidal habitat to allow maintenance and harvesting at low tide, as well as to reduce biofouling. The pens are basically designed to encase the seed clams from the sides and above with a mesh small enough to reduce predation losses during the growout period. Harvesting can be done by lifting the pen from atop the protected bottom area and removing the clams by hand, rakes, or with allowable mechanical harvesting methods.

Trays can assume a variety of forms, but typically fall within two general designs: rigid and soft trays. *Rigid* trays are box-like structures made of treated wood or plastic for the sides and bottom. A layer of sand is placed in the tray; the seed clams are distributed over the sand; and a protective mesh screen, which covers the top of the tray, is attached. The tray is placed on the bottom in intertidal or subtidal habitats. If the trays are placed in a subtidal area, each unit must be lifted off the bottom for harvest. Trays containing a load of wet sediment and harvest-sized clams can be quite heavy. Harvesting in this manner will require some form of sturdy lifting apparatus. Trays placed in intertidal areas, however, can be serviced and harvested in the same manner as an intertidal pen. Soft trays were designed to embody the positive attributes of the general tray design, but reduce the expense and inconvenience of rigid trays. *Soft* trays are essentially bags or "pillows" constructed of a flexible plastic mesh approximately four ft square. Seed clams are placed inside the bag and the unit placed on suitable bottom. A float may be initially attached to the center of the top side to allow the bag to "tent" and siltation to thinly cover the clams. The bag can be flipped over periodically to reduce the fouling on the exposed side and keep siltation from getting too heavy. Harvesting is accomplished by lifting the entire bag off the bottom, allowing the collected sediment to fall through the bag mesh and retaining only the clams inside the bag. The bag can then be emptied on site or carried to a shoreside facility.

Nets are the most simplistic in design and least expensive to build of the growout methods. Nets are employed by distributing seed clams over a section of bottom in the dimensions of the net to be used. Once the seed clams are broadcast, the net is simply positioned over the planted area and staked down on the sides and corners. A weighted line is attached to the full length of each side to help the sides settle into the substrate, further discouraging predators. Bottom nets are typically utilized in sizes of approximately 8 to 10 ft wide by 25 to 50 ft in length. Harvesting is accomplished by rolling the nets back from over the planted area and exposing the clams to harvest by allowable harvesting means.

One of the most important factors relative to the feasibility of hard clam aquaculture in the southeastern United States has been the availability of larger seed clams. The availability of seed in sufficient quantity allowed for rapid improvements in growout technology. As a result, techniques have been refined for traditional growout methods, such as pens and hard trays. In addition, new methods have also been developed, such as soft trays, bottom nets, and belt systems. A better understanding of appropriate methods for specific habitats has also been achieved. The development of these new methods focused on reducing initial investment costs, replacement and repair expenses, and labor requirements. As a result, these cost categories for hard clam aquaculture, particularly for growout, are low relative to some other forms of shellfish and finfish aquaculture.

Relative investment/ operation costs

Costs of construction and operation can vary greatly between the various nursery and growout systems. In addition, the financial performance of each system can also vary considerably when examined as a separate stand-alone operation (i.e. the nursery and growout each producing seed and market clams, respectively, for sale without being vertically integrated with the other). The following discussion will first identify some of the economic factors which characterize each of the various hard clam nursery and growout systems. The hatchery is not discussed since spawning and larval rearing activities are likely not compatible with the containment area pond environment.

Nursery Cost Comparisons. The alternative nursery systems vary considerably in terms of investment costs, operational expenses, and requisite management skills (Table 1). The land-based systems require considerable investment or lease cost in waterfront land. The land-based systems also require an investment in pumps whereas the field-based systems are located on leased bottom without the need for controlled water movement (with the possible exception of a floating pen system). Therefore, energy requirements are much higher for the land-based systems. Initial capital costs are also much higher for the land-based systems because of the need for some form of shoreside facility. Maintenance costs are lower for the upflow systems, because the required apparatus is constructed primarily of plastic and PVC pipe, whereas the raceways are of wooden construction. Replacement and maintenance costs are higher for the field-tray systems because of being located in the water and subjected to damage by predators, fouling, and wave action. However, among these field-based designs, the use of soft trays can significantly reduce maintenance and labor expenses. Survival rates are much higher for the land-based systems due to greater potential control over water quality and lack of predators.

Growout Cost Comparisons. As with the nursery systems, the various growout systems are characterized by differing costs of investment and operation (Table 2). Since nets are basically constructed of only netting, weights, and stakes, the costs of initial investment are low compared to pens and rigid trays. Though inexpensive to build, wooden trays can be susceptible to marine borers, which may result in the need for frequent replacement. Soft trays are inexpensive to construct, easy to handle and harvest, and require only minor maintenance. Maintenance costs are also minimal for bottom nets, but nets may also be more susceptible to predators than other growout methods. Pens and trays confine the clams to relatively small areas and allow for relative ease in harvesting large numbers of clams. Harvesting bottom nets must be done by hand or rake over an area which is relatively large compared to the other growout units. In addition, labor required to inspect intertidal pens and trays are low due to periodic ease of access whereas subtidal trays and nets are always submerged, making inspection for predation, fouling and repairs more difficult.

Table 1
Economic Factors Which Determine the Appropriate Hard Clam Nursery Culture Systems

Critical Factors	System Type: Raceways	Upflows	Cages/Trays
Location	Landbased and adjacent to a source of high quality seawater	Landbased and adjacent to a source of high quality seawater	Fieldbased in low intertidal or shallow subtidal protected estuarine areas
Maintenance Requirement	High	Low	Moderate to High (site specific)
Initial Capital Costs	High	High	Low
Replacement Costs	Low	High	Moderate to High
Energy Requirement (utilities)	High	High	Low
Survival Rates	High	High	Low to Moderate

Source: Adams, et al. (1991).

Table 2
Economic Factors Which Determine the Appropriate Hard Clam Growout Systems

Critical Factors	System Type: Pens	Trays	Nets
Location	Intertidal	Intertidal, Subtidal	Subtidal
Sediment	Soft Bottoms, Mud	Hard Bottoms, Sand	Hard Bottoms, Sand
Maintenance Requirement	Moderate	Moderate to High	Low
Capital Costs	High	High	Low
Labor to Harvest	Moderate	Low	High
Effort to Access and Inspect	Low	Moderate	High
Recommended Method by State:			
Virginia		X	X
North Carolina		X	X
South Carolina	X	X	
Georgia	X	X	X
Florida		X	

Source: Adams et al. (1991).

Financial Performance

A recent National Coastal Resources Institute and Florida Sea Grant funded study generated a detailed financial analysis describing a variety of hard clam hatchery, nursery, and growout systems (Adams et al. 1991). This analysis examined these systems as standalone operations, as well as systems integrated from hatchery through growout phases for selected methods. The following discussion draws heavily from that report.

A number of financial statements and related information were generated for each alternative production system. The financial analysis was based on a number of underlying assumptions. Some of the more important assumptions include:

- Production:
  * Nursery systems operate only six months per year.
  * Growout period length is 36 months.
  * Mortality is assumed to be 50 percent.
  * Growout systems are stocked at a density of 100 seed clams per square foot.
  * Respective harvest sizes are nursery (15 mm) and growout (50 mm), with all harvested at a given size.

- Financial:
  * Harvest volumes and prices (output and input) are constant.
  * Interest rates on loans are 12 percent (capital loans are for 10 years).
  * 35 percent owner financing required (12 percent opportunity cost charged against owner equity).
  * Straight-line depreciation is used.
  * An operating loan covers all cash shortfalls.
  * Income is before taxes and final returns are to owner-operator management and risk.
  * Cost of acquiring waterfront property is not included.

A number of other assumptions pertain to discount rates, repair and maintenance, variable expenses, lease fees, and other overhead costs, production scheduling, and technical aspects of production. These "baseline" assumptions (derived through extensive interviews with current producers and academic/institutional researchers) are considered to impose favorable, yet conservative and static, conditions on the production process.

The following discussion will briefly assess the specific initial investment requirements, annual fixed and variable costs, and financial performance for the stand-alone field-tray nursery and the soft tray growout systems. Only these two systems will be highlighted, due to the potential suitability of each system for field-based containment area aquaculture operations. The reader should consult Adams et al. (1991) for a more complete and detailed discussion of the analysis.

Field-Tray Nursery System. Initial capital investment requirements for the field-tray system are substantially less than for land-based systems. The example utilized here is designed to produce 12 million 15-mm seed clams. Whereas the land-based systems have major investments in shoreside facilities, the majority of the capital expenses for the field tray system are directed toward tray maintenance and harvesting the bottom leases (Table 3). Major capital requirements include the trays (2.5 ft by 4 ft), barge/shaker, and dock. The barge must be big enough to accommodate temporary storage of trays and gravel/sand, as well as have enough deck space for a mechanical shaker for sorting. The dock must be large enough for movement of trays and equipment on and off the barge during harvesting, including a front-end loader to move gravel/sand from onshore storage sites. A total of 550 trays are required for initial stocking of seed. A quarter-acre bottom lease would be necessary. Initial investment requirements are $80,250. Significant capital replacement is also required for the boat, motor, and trailer needed to tend the trays in the field.

The operational expenses for the field-tray system are approximately twice as large as those estimated for the upflow system. Differences include costs of operation and maintenance of the barge, boat, and motors, as well as additional labor for tending and harvesting the trays. The system is assumed to require three full-time laborers and a technician for six months, in addition to the owner-operator. However, the major operational expense is the cost of seed clam acquisition (Table 4). Instead of stocking 1-mm seed in shoreside upwellers for the upflow nursery, the field-tray system is assumed to stock 3-mm seed, which will be more costly to obtain from a commercial hatchery. However, because the seed is stocked at a larger size, anticipated mortality is reduced to only 25 percent. Therefore, 16 million seed clams are required for the target output of 12 million market clams. The price for 3-mm seed clams is assumed to be $0.01 each, annually totaling $160,000. Total annual operating expenses are estimated at $206,525 for year three and beyond.

The seed clams produced by the field-tray system are larger (15 mm) than those produced by the upflow system (8 mm), as they are stocked in the trays at a larger initial size. The anticipated market price for the 15-mm seed clams is $0.03 each, resulting in an

Table 3
Initial Investment and Capital Asset Addition Schedule for Hard Clam Nursery System - Field-tray Method (12 Million Harvest Capacity)

Systems/ Equipment	Years of Life	No.	Initial Invest-ment, Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Land	—	½ ac	—	—	—	—	—	—	—	—	—	—
Shed	15	1	800	—	—	—	—	—	—	—	—	—
Trays	10	550	13,750	—	—	—	—	—	—	—	—	—
Barge/ Mechancical Shaker	10	1	18,000	—	—	—	—	—	—	—	—	—
Pump	1	5 hp	500	500	500	500	500	500	500	500	500	500
Boat	8	1	7,000	—	—	—	—	—	—	7,000	—	—
Motor	3	1	4,000	—	—	4,000	—	—	4,000	--	4,000	—
Trailer	3	1	1,000	—	—	1,000	—	—	1,000	—	1,000	—
Wet Suits	2	4	1,200	—	1,200	—	1,200	—	1,200	1,200	—	—
Dock	20	1	16,000	—	—	—	—	—	—	—	—	—
Pickup	5	1	8,000	—	—	—	—	8,000	—	—	—	—
Front-End Loader	10	1	9,000	—	—	—	—	—	—	—	—	—
Miscellaneous Equipment	3	—	1,000	—	—	1,000	—	—	1,000	—	1,000	—
Total Nursery			$80,250	500	1,700	8,500	7,700	8,700	6,500	500		

Table 4
Annual Operating Expenses for Hard Clam Nursery System - Field-tray Method (12 Million Seed Output Capacity)

Production Costs	
Lights	$ 200
Clam Seed (16 million 3mm @ $.01 ea.)	160,000
Supplies & Expenditures	1,000
Tray Repair & Maintenance	700
Repair & Maintenance	
Truck	800
Boat & Motor	1,200
Barge & Shaker	1,800
Front-end Loader & Pump	950
Fuel and Oil	
Truck	1,000
Boat & Motor	750
Front-end Loader	500
Packaging Materials	1,000
Salaries and Wages	
Technician Salary	8,000
Benefits	1,000
Labor	18,750
Benefits	1,875
Overhead	
Insurance	2,000
Miscellaneous Costs	5,000
Total	$206,525

annual total revenue of $360,000. Given the assumptions regarding operating expenses and debt retirement, this relatively large annual revenue produces a positive cash position for every year in the 10-year plan (Table 5). As with the upflow system, no operating loan is required. NPV for the field-tray system is estimated to be approximately $3 million, while IRR is estimated to be in excess of 200 percent! The income statement for year five further indicates a positive net return of $133,138, after depreciation and opportunity costs (Table 6). This high IRR reflects the "favorable" conditions imposed by the set of base assumptions.

An annual enterprise budget for the field-tray system is presented in Table 7. The budget describes the costs, earnings, net returns, and other values of financial interest. Some of these values are also found on the income statement. The budget pertains to year five in the planning horizon. Note that the cost per clam is $0.019 and the break-even survival rate is 46 percent.

Table 5
Annual Cash Flow for Hard Clam Nursery System - Field-tray Method (12 Million Harvest Capacity)

	Year									
	1	2	3	4	5	6	7	8	9	10
Beginning cash balance	$ 0	131,850	269,809	413,663	556,366	698,768	839,667	979,202	1,118,649	1,256,555
Total cash receipts	360,000	360,000	360,000	360,000	360,000	360,000	360,000	360,000	360,000	360,000
Total cash outflow										
Operating expenses	218,917	212,721	205,525	206,525	206,525	206,525	206,525	206,525	206,525	206,525
Long-term loan payment										
Principal	2,972	3,358	3,358	4,691	5,351	6,476	7,692	8,645	10,178	11,769
Interest	6,260	5,963	5,763	6,081	5,722	6,100	6,247	5,384	5,390	4,949
Total	228,149	222,042	216,146	217,297	217,297	219,102	220,464	220,533	222,093	233,243
Cash available	131,850	269,809	413,663	556,366	698,768	839,667	979,202	1,118,649	1,256,555	1,393,312
New operating loan										
Operating loan payment	0	0	0	0	0	0	0	0	0	0
Principal	0	0	0	0	0	0	0	0	0	0
Interest	12,392	6,196	0	0	0	0	0	0	0	0
Ending cash balance	131,850	269,809	413,663	556,366	698,768	839,667	979,202	1,118,649	1,256,555	1,393,312
Summary of debt outstanding										
Long-term debt balance[1]	49,690	48,033	50,675	47,685	50,834	52,057	44,864	44,920	41,242	29,473
Operating debt balance	0	0	0	0	0	0	0	0	0	0
Interest on operating debt	12,392	6,196	0	0	0	0	0	0	0	0

[1] Initial long-term loan balance – $52,163.

Table 6
Income Statement (Year Five) for Hard Clam Nursery Field-tray Method (12 Million Harvest Capacity)

Revenues	$360,000
Operating expenses	206,525
Long-term loan payment: Interest	5,722
Operating loan payment: Interest	0
Depreciation	10,044
Net returns to owner's capital, management and risk	$137,709
Opportunity cost of initial owner equity	4,571
Net returns to owner's management and risk	$133,138

Table 7
General Enterprise Budget (Year 5) for Hard Clam Field-tray Nursery System (12 Million Harvest Capacity)

Revenues		Estimated Value
12 Million 15 mm @ $0.03 ea.		$170,000
Operating Expenses		
Variable Costs:	$160,000	
Seed Clams (16 million 3 mm @ $0.03 ea)	1,000	
Supplies and Expendables		
Fuel/Oil		
Boat/Motor	750	
Truck	1,000	
Front-end Loader	500	
Maintenance		
Boat/Truck	2,000	
Barge/Shaker	1,800	
Front-end Loader/Pump	950	
Labor/Salaries	29,625	
Total Variable Costs		$197,625
Fixed Costs		
Overhead		
Insurance	$ 2,000	
Miscellaneous	5,000	
Long-term Debt Interest	5,722	
Operating Debt Interest	0	
Depreciation	10,044	
Total Fixed Costs		$ 22,766
Net Returns Before Tax to Owner/Operator Capital, Management, and Risk		$139,609
Opportunity Cost of Initial Owner Equity		$ 4,571
Net Returns Before Tax to Owner/Operator Management and Risk		$135,038
Cost per Clam and Break-even Price[1]		$ 0.019
Margin per Clam[2]		$ 0.012
Break-even Survival Rate[3]		46%

[1] The sum to total variable and fixed costs divided by number of clams harvested (i.e., 12 million).
[2] Difference between break-even price and actual selling price (i.e., $0.03).
[3] The sum of total variable and fixed costs divided by selling price, then divided by initial number of clams stocked (i.e., 16 million).

Soft-Tray Growout System. The soft-tray system is assumed to produce one million 45- to 50-mm littleneck clams with a selling price of $0.17 each. Plantings occur in the first three years to maintain constant production in year three and beyond. The growout period is 24 to 36 months. The initial capital investment required for the soft-tray system is $38,037. The major capital expense is for the 4- by 4-ft soft trays or bags made of plastic mesh (Table 8). Basically, the process involves two steps. A specific mesh size is required to grow the clams from 8 mm to 15 mm while another is required to grow the clams from 15 mm to 50 mm. A total of 156 small and 1,250 large mesh bags is needed for this size operation. A constant level of production is attained by putting an additional complement of trays into production in year two and three. A boat, motor and trailer are required for tray maintenance and harvest. The trays are also given only a three-year life. The replacement of the trays, due to damage from handling and predators, results in a significant annual cost for year four and beyond.

Total operating expenses for the system are $47,250 in year three. The acquisition of seed for stocking is the largest single production cost (Table 9). Fuel, oil and maintenance costs represent additional significant production costs.

A positive ending cash balance occurs for years four and beyond (Table 10). Returns above the operating costs for year three are not sufficient to retire the operating loans incurred during years one, two and three. Positive net cash flow occurs during years four through ten. The soft tray system produces a 10-year NPV of $87(261, with an estimated IRR of 84 percent. These values reflect the favorable base assumptions. Returns above operating costs, debt, depreciation and opportunity costs for year five are $96,814 (Table 11).

An annual enterprise budget for the soft-tray system is presented in Table 12. Some of these values are also found on the income statement, yet given in more detail in the annual budget. Note that the cost per clam is $0.069, well below market price, and the break-even survival rate is 20 percent.

Oyster Culture

Industry History

Technical interest in oyster culture in the United States dates back to the late 1800's. However, as with clam culture, success in rearing larval oysters (*Crassostrea virginica*) did not occur until the 1920's (Bardach and Ryther 1972). Artificially induced spawning was first incorporated into the hatchery culture process in the 1940's. Since then, many technical improvements have been achieved and standardized in terms of larval and juvenile culture, and growout culture methods. It is estimated that 13 thousand tons of oysters (all species) were cultured in the United States in 1987 (*Aquaculture* 1990).

Production Methods

Most of the current culture techniques employed for *C. virginica* are linked to some form of bottom growout. Few oysters cultured in the southeastern U.S. region are done so utilizing an off-bottom or suspended method. Some experimental efforts have been directed toward raft, stake, or suspended rope culture. Off-bottom methods offer the advantages of increased growth and reduced predation (Landau 1991). However, these methods have not met with much economic success and may have limited applicability due to conflicts with existing water column property rights and navigational restrictions (Thunberg et al. 1990). The most widespread method of culturing oysters in the region is to collect oyster spat on some form of clean, hard substrate, such as oyster shell. Typically, the substrate is placed on the bottom to allow larval oysters an opportunity to attach to the substrate. Alternatively, seeded cultch can be purchased from an existing hatchery. The seeded substrate remains on the bottom for a sufficient period of time so as to allow the oysters to reach market size. The oysters are then harvested by hand or allowable mechanized harvesting methods.

Table 8
Initial Investment and Capital Asset Addition Schedule for Hard Clam Soft-tray Growout (1 Million Harvest capacity)

Systems/ Equipment	Years of Life	No.	Initial In-vestment Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Bags (4 ft by 4 ft)												
Small Mesh	3	156	$ 2,262	$ 2,262	$ 2,262	$ 2,262	$ 2,262	$ 2,262	$ 2,262	$ 2,262	$ 2,262	$ 2,262
Large Mesh	3	1,250	15,813	15,813	15,813	15,813	15,813	15,813	15,813	15,813	15,813	15,813
Floats	1	1,406	562	562	562	562	562	562	562	562	562	562
Wet suit/scuba	2	1	1,100	—	1,100	—	1,100	—	1,100	—	1,100	—
Boat	8	1	6,500	—	—	—	—	—	—	—	6,500	—
Motor	3	1	2,000	—	—	—	—	2,000	—	—	—	2,000
Trailer	3	1	1,000	—	—	—	—	1,000	—	—	—	1,000
Bag cleaning tank	3	—	200	—	—	—	—	—	—	—	—	—
Pick-up truck	5	1	8,000	—	—	—	—	—	—	8,000	—	—
Miscellaneous equipment	2	—	600	—	600	—	600	—	600	—	600	—
Total			$38,037	18,637	20,337	21,637	20,337	26,637	23,337	18,637	26,837	21,637

Table 9 **Operating Expenses for a Hard Clam Soft-tray Growout (1 Million Harvest Capacity)**						
	Year					
	1	**2**	**3**	**4**	**5**	**6**
Production Costs:						
Seed (8mm)	$40,000	40,000	40,000	40,000	40,000	40,000
Supplies/Expendables	100	120	140	140	140	140
Fuel/Oil						
Boat	700	800	900	900	900	900
Truck	600	800	1,000	1,000	1,000	1,000
Maintenance						
Boat/Truck	950	950	950	950	950	950
Trays	900	900	900	900	900	900
Harvest Bags	0	0	1,000	1,000	1,000	1,000
Salary and Wages	—	—	—	—	—	—
Overhead:						
Insurance	1,000	1,000	1,000	1,000	1,000	1,000
Miscellaneous Costs	1,300	1,300	1,360	1,360	1,360	1,360
Total	$45,550	45,900	47,250	47,250	47,250	47,250

The growout period can range from two to five years, depending on water quality and temperature in the specific location.

The following discussion will focus on a more recent growout method developed by the Harbor Branch Oceanographic Institute. This technique, referred to as the flexible-belt system, has been designed for subtidal habitats found in Florida. However, the method may also be applicable in other states where similar subtidal environments exist. The hatchery and nursery techniques utilized are very similar to the upweller systems employed for hard clam culture and will not be discussed in detail. One point to be made is that the hatchery process produces a cultchless seed oyster. The larval oyster binds to a small substrate fragment, which prevents further clustering. This will allow the oyster to reach market size as a separate individual with minimal shell deformation. This characteristic may also allow the cultchless oyster to generate a premium price in the shell-stock market.

Flexible-belt Growout. The flexible-belt system incorporates some of the positive attributes of off-bottom culture methods, while extending only six inches from the bottom surface. The design and production methods for the flexible-belt system are documented in Creswell, Holt, and Vaughan (1989) and Creswell, Vaughan, and Sturmer (1990). The system resembles a ladder constructed of flexible PVC piping with plastic mesh bags attached between the rungs of the ladder. Seed oysters are initially placed in the mesh bags as they emerge from the hatchery. The seed oysters are kept in nursery bags (two different mesh sizes) until they achieve a certain size. As the oysters increase in size, they are placed in growout bags (three different mesh sizes) constructed of a larger mesh. During the growout period, the bags are continually cleaned of any fouling and the oysters are periodically sorted by size and placed in the appropriate nursery or growout bag. The belt is anchored to the bottom and lifted only for periodic handling and harvesting. The flexible-belt system offers several distinct advantages (Thunberg et al. 1990):

- The entire belt is constructed of rope, PVC, and nylon bags. This makes the belt light, durable, easy to handle, and relatively inexpensive.
- The oysters can be moved or handled by simply bringing the belt to the surface. The belt can be handled on-site

Table 10
Annual Cash Flow for Hard Clam Soft-tray Method (1 Million Harvest Capacity)

	Year									
	1	2	3	4	5	6	7	8	9	10
Beginning cash balance	$ 0	0	0	0	95,155	199,203	298,536	393,739	485,644	562,799
Total cash receipts	0	0	170,000	170,000	170,000	170,000	170,000	170,000	170,000	170,000
Total cash outflow										
Operating expenses	45,550	45,900	47,250	47,250	47,250	47,250	47,250	47,250	47,250	47,250
Long-term loan payment										
Principal	1,409	2,640	4,116	5,842	7,702	10,145	12,692	15,277	18,639	22,109
Interest	2,957	5,034	7,158	9,260	11,000	13,272	14,855	15,568	16,956	17,315
Total	49,916	53,574	58,524	62,352	65,592	70,667	74,797	78,095	82,845	86,674
Cash available	(49,916)	(53,574)	111,476	107,647	199,203	298,536	393,739	485,644	572,799	656,125
New operating loan	49,925	53,574	0	0	0	0	0	0	0	0
Operating loan payment	0	0	111,476	12,492	0	0	0	0	0	0
Ending cash balance	0	0	0	95,155	199,203	298,536	393,739	485,644	572,799	656,125
Summary of debt outstanding										
Long-term debt balance[1]	23,315	39,319	55,533	71,329	83,963	100,455	111,100	114,460	122,658	122,186
Operating debt balance	49,926	109,491	11,154	0	0	0	0	0	0	0
Interest on operating debt	5,991	13,139	1,338	0	0	0	0	0	0	0

[1] Initial long-term loan balance – $24,724.

Table 11 **Income Statemen (Year Five) for Hard Clam Soft-tray Growout (1 Million Harvest Capacity)**	
Revenues	$170,000
Operating expenses	47,250
Long-term loan payment: Interest	11,000
Operating loan payment: Interest	0
Depreciation	10,860
Net returns to owner's capital, management and risk	100,890
Opportunity cost of initial owner equity	4,076
Net returns to owner's management and risk	96,814

Table 12
General Enterprise Budget (Year 5) for Hard Clam Soft-tray Growout System (1 Million Harvest Capacity)

Revenues		Estimated Value
1 Million 45-50 mm @ $0.17 ea.		$170,000
Operating Expenses		
Variable Costs:		
Seed Clams (2 million 8 mm @ $0.02 ea)	$40,000	
Supplies and Expendables	140	
Fuel/Oil		
Boat	900	
Truck	1,000	
Maintenance		
Boat/Truck	950	
Trays	900	
Harvest Bags	1,000	
Labor	0	
Total Variable Costs		$ 44,890
Fixed Costs		
Overhead		
Insurance	$ 1,000	
Miscellaneous	1,360	
Long-term Debt Interest	11,000	
Operating Debt Interest	0	
Depreciation	10,860	
Total Fixed Costs		$ 24,220
Net Returns Before Tax to Owner/Operator Capital, Management, and Risk		$100,890
Opportunity Cost of Initial Owner Equity		$ 4,076
Net Returns Before Tax to Owner/Operator Management and Risk		$ 96,814
Cost per Clam and Break-even Price[1]		$ 0.06
Margin per Clam[2]		$ 0.10
Break-even Survival Rate[3]		20%

[1] The sum to total variable and fixed costs divided by number of clams harvested (i.e., 1 million).
[2] Difference between break-even price and actual selling price (i.e., $0.17).
[3] The sum of total variable and fixed costs divided by selling price, then divided by initial number of clams stocked (i.e., 2 million).

by detaching one anchor and maneuvering the belt onto a PVC ramp or specially designed vessel. The ramp is then pulled along the entire length of the belt with each progressive bag being brought to the surface. The oysters can then be cleaned, sampled, sorted, and allowed to return to the bottom as one proceeds down the belt. (Management of the flexible-belt system requires periodic cleaning of the bags and monitoring of the growing oysters to assure proper stocking densities and optimal growing conditions).

- Harvesting of the oysters can be accomplished by raising the belt and removing the oysters from each bag. Harvesting in this manner reduces labor requirements and reduces harvest costs.

- The oysters are retained at all times in a nylon mesh bag and are protected from benthic and free-swimming predators. Protection from predation reduces mortality and increases yield at harvest time.

- The flexible-belt system produces a cultchless oyster that is uniform in size and shape. Such an oyster may be regarded as a premium product for restaurants and the raw bar trade.

Investment/Operation Costs

The following discussion pertains to an operation which utilizes 1/4 acre of submerged bottom. Although the production methods for the flexible-belt systems are well documented and standardized, there are currently no commercial operations in existence. Therefore, the following cost and revenue estimates are hypothetical in nature. A number of assumptions are imposed in the analysis, which include:

- One-quarter acre of submerged bottom is required.

- 4.5 belts using 144 bags per belt are used.

- A fifteen month growout period is required.

- A uniform 97 percent monthly survival rate is assumed. Thus, 65 percent of all seed originally planted will be harvested in month 15.

- Oysters grow at a uniform rate.

- A market price of $0.18 per oyster is assumed.

- A 60-month continuous production schedule is assumed where seed oysters are planted in month 1, 5, and every fourth month thereafter.

- 125,000 seed oysters are planted during each plant.

- Capital investment is financed by a five-year loan at a 10.5 percent interest rate.

- Cash shortfalls are covered by an operating loan financed at a 11 percent rate of interest.

- The operation is managed by a single owner-operator.

A number of other assumptions are imposed and these are discussed in detail in Thunberg et al. (1990).

The initial capital and equipment investment for the 1/4 acre operation is given in Table 13. The total investment cost for all materials for the belt system is $3,577. The total number of bags of all sizes cannot exceed 648, due to the assumed size of the lease and the belt dimensions. Given the planting rate assumption, only 638 bags will be needed. Capital equipment, other than for bags, totals $13,700. Operational support equipment and the cost of obtaining a lease are estimated to be $192 and $5,000, respectively. The total initial capital investment is estimated to be $22,470. Total operating expenses for each year is $7,473, of which $5,625 is the cost for seed oysters, with the remainder being allocated to equipment and bag repairs and fuel/oil (Table 14). Given the 15-month growout period, cash receipts are not realized until the second year. Net returns to owner labor, risk, and management in year two is $29,791. As debt and interest expenses are reduced, the annual net income continues to increase, reaching $31,782 in year five.

Table 13
Capital Investment Requirements, Oyster Flexible-Belt System (¼-acre operation)

	Unit Cost, dollars	Quantity	Total Cost, dollars	
Materials for Flexible Bag				
Bags				
Nursery Bag 1 (each)	2.65	13.00	34.45	
Nursery Bag 2 (each)	2.65	30.00	79.50	
Nursery Bag 1 (each)	2.65	76.00	201.40	
Nursery Bag 2 (each)	2.65	202.00	535.30	
Nursery Bag 3 (each)	2.65	358.00	948.70	
Closures (each)	0.34	1,296.00	440.64	
Spacers (each)	1.54	648.00	997.92	
Rope (feet)	0.06	4,000.00	240.00	
Floats (each)	5.00	10.00	50.00	
Anchors (each)	4.95	10.00	49.50	
				3,577.41
Capital Equipment				
Push Ramp (each)	200.00	1.00	200.00	
Boat, Motor (each)	1,500.00	1.00	1,500.00	
Truck (each)	10,000.00	1.00	10,000.00	
Storage	1,000.00	1.00	1,000.00	
Work Area	1,000.00	1.00	1,000.00	
				13,700.00
Operational Support Equipment				
Wet Suit (each)	50.00	1.00	50.00	
Buckets (each)	2.50	5.00	12.50	
Brushes (each)	0.50	15.00	7.50	
Volumetric Measures (each)	2.50	5.00	12.50	
Sieves (each)	3.00	5.00	15.00	
Gloves/Boots (each)	15.00	4.00	60.00	
Record Keeping Materials (each)	35.00	1.00	35.00	
Lease	5,000.00	1.00	5,000.00	
			Total	22,469.91

Table 14
Annual Income Statement (¼-acre operation)

	Year 1	Year 2	Year 3	Year 4	Year 5
Cash receipts	0.00	44,066.45	44,066.45	44,066.45	44,066.45
Cash expenses					
Seed oysters	5,625.00	5,625.00	5,625.00	5,625.00	5,625.00
Hired labor	0.00	0.00	0.00	0.00	0.00
Repairs	1,548.87	1,548.87	1,548.87	1,548.87	1,548.87
Fuel and oil	300.00	300.00	300.00	300.00	300.00
Taxes					
Insurance					
Interest	3,088.87	2,307.52	1,350.34	860.46	316.59
Noncash expenses depreciation (over 5 years)	4,493.98	4,493.98	4,493.98	4,493.98	4,493.98
Total cost	15,056.72	14,275.37	13,318.20	12,828.32	12,284.45

Implications of Siting Current Hard Clam and Oyster Culture Technologies in Containment Area Ponds

The nursery and grow-out technologies previously described were designed primarily for use in a shoreside or open-water setting. For those designed for application in an open-water environment, natural tidal fluctuations and wave action are assumed to provide for the necessary water exchange, oxygenation, and algal nourishment. The systems have also been designed to resist the adverse effects of normal wave surge, siltation, predation, and other factors. These factors have been considered in the design of both subtidal and intertidal systems. In addition, features which recognized restrictions related to allowable culture techniques in navigable public waterways have been incorporated. However, some of these design elements may be unnecessary, or in need of modification, when the respective system is placed in the semi-controlled environment of a privately owned containment area pond. As a result, initial capital investment, debt retirement costs, variable costs of operation, culture technique, anticipated mortality rates, grow-out period length, and other factors may change significantly when the intertidal and subtidal environment is exchanged for that of an enclosed pond. This will likely be true whether the culture operation produces hard clams or oysters. The following discussion focuses on the likely advantages and disadvantages of bivalve nursery and growout culture in containment area ponds, as opposed to open-water or shoreside systems.

Potential disadvantages

The major difference between open water and pond nursery and growout systems will be the need to exercise control over water quality. These concerns will certainly not be unique to bivalve culture in containment areas. For example, water temperature, oxygen levels, and salinity will need to be closely monitored. Some means to periodically exchange water, as well as keep water moving to avoid stratification, will be required. A water distribution/pumping system with enough capacity to lift water over the containment area levee will be required. In addition, an in-pond pumping system may be required to ensure the shallow-water pond environment does not stratify, an obviously serious development for the bottom culture of bivalves in a closed-pond setting. Two horsepower per acre may be adequate to generate one knot of current (Vaughn, D.E., personal communication). However, the exact requirements given the characteristics of a specific pond would need to be determined. Water exchange will also be required to ensure an adequate algal bloom exists in the pond at all times. Some fertilization may be periodically required, although the high photic zone of the pond may be adequate to maintain sufficient algal blooms. Aeration devices may be needed to maintain acceptable oxygen levels. Considerable energy may be required to maintain adequate water quality. Each of these considerations - water exchange, oxygen, algal supply - require capital investment, variable costs, and managerial/technical skill that may exceed the requirements for open-water applications. Unless production can be increased to offset these additional costs, the profitability of the current technology may be reduced. From the perspective of cost versus water quality, the application of the current open-water hard clam and oyster technologies in a containment area pond setting may be at a disadvantage. This may be particularly true from the grow-out perspective since costs for water quality management in an open-water setting are virtually zero.

Excessive silt loading may be a recurrent problem if the pond system is actively utilized for spoil disposal. Excessive siltation can introduce the risk of suffocation for both oysters and clams, thereby restricting the culturist to the use of off-bottom culture systems or requiring the use of more labor to continually monitor sediment buildup. Ongoing research in the southeastern United States is currently assessing the feasibility of stake culture and stacked-tray culture of oysters. However, off-bottom culture technologies, such as floating pen systems, have only recently been developed for hard clam nursery operations.

Although floating pen systems may have specific advantages, the performance of these systems from an economic and financial perspective have not yet been assessed. Floating pen systems, which are suspended high in the photic zone, are susceptible to biofouling. This may require continuous cleaning (additional cost of labor) or the utilization of pen covers (additional capital investment) that restrict the exposure of the floating pen system to direct sunlight.

The acquisition and permitting of coastal lands for containment area construction may be problematic in some states. Current zoning restrictions may exist that prohibit the utilization of certain coastal properties for containment area development and aquaculture uses. The use of properties with preexisting coastal mosquito control impoundments, which are zoned only for residential use, has proven to be problematic for prospective commercial aquaculturists on the east coast of Florida (St. Lucie County Board of County Commissioners 1988). Such potential land-use policy impediments may provide a significant constraint to the availability of suitable land for containment area aquaculture.

Potential advantages

The controlled environment of the containment area pond will afford certain advantages. One of these is predator control, which is a major source of mortality and maintenance costs for open-water systems. Loss to predators will likely be significantly reduced in the pond environment as the affluent water will be filtered to remove adult and juvenile crabs, finfish, and other potential predator species. However, some predation will likely occur as control measures are often not totally foolproof. To further reduce the threat of predation, off-bottom culture methods may be more appropriate. This may be of particular interest to nursery operations. The utilization of such techniques may be possible in privately owned ponds whereas they may not be allowed in public waters due to navigational and other restrictions.

Although not documented, the initial capital investment requirements for a floating pen nursery system will be significantly lower than a shoreside nursery facility of comparable capacity, but higher (due to the need for a water distribution system) than a field-based pen or tray nursery system. In addition, mortality rates may be higher for the pond floating system, which exists in an environment less directly controlled by the culturist than the shoreside facility.

A floating system will also have reduced energy requirements relative to water movement as compared to the shoreside facility. With respect to the former, water need only be moved a few inches vertically to clear the above-water profile of the floating culture unit. A small submerged fan-style pump may suffice. In contrast, the shoreside facility must overcome significant head loss as the water is moved "uphill" to the facility. Considerable investment in pumping systems is required. Previous studies have indicated that pumps represent at least 25 percent of the initial capital investment and annual operating expenses of shoreside nursery systems (Adams et al. 1991).

The shallow-water environment of the pond may be conducive to increased growth rates. This may be possible if the pond water can be maintained at higher temperatures than found in ambient open-water systems. However, the avoidance of lethal temperature extremes will require incurring the cost of water movement and exchange.

Polyculture may also be possible in the confined quarters of the containment area pond. Production in the pond may be staggered in terms of species to take advantage of seasonally changing environmental conditions. Recent research underway at the Waddell Mariculture Center in South Carolina has examined the joint culture of shrimp and oysters in a pond setting.

Further considerations

Recent increased concern for seafood safety, particularly as related to raw shellfish consumption, has prompted state and federal agencies to adopt a more cautious attitude toward water quality in public shellfish producing areas. This increased concern may provide an interesting challenge to the development of the pond culture of bivalves in the United States.

The water quality within the containment area pond environment, in terms of potential chemical contaminants and bacterial/viral pathogens, may pose a serious concern. The pond may prove to be an environment conducive to levels of fecal coliforms and *Vibrio* bacteria higher than found in natural areas. A containment area pond may be characterized by high levels of suspended solids (especially if the containment area is periodically utilized for dredge disposal). Also, the shallow nature of the pond may produce high water temperatures. In addition, potential exists for the pond, unless properly constructed, to act as a watershed sink which could further introduce unwanted nutrients, pathogens, and contaminants from surrounding areas. These conditions - high temperatures (due to shallow water, with a long retention time, and exposure of suspended solids to sunlight), excessive nutrients from runoff, and the high total surface (growing) area provided by suspended solids - may generate bacterial/viral growing conditions which could lead to elevated levels of these pathogens. Finally, the spoil with which the containment area pond is constructed and designed to contain may itself be a potential source of chemical contaminants. The question is, "How will the agencies who approve waters for shellfish harvest view the pond environment in terms of bivalve culture with the eventual intent for human consumption?"

The National Shellfish Sanitation Program (NSSP), as administered by the Food and Drug Administration (FDA) in cooperation with the Interstate Shellfish Sanitation Conference (ISSC), provides standards of sanitation which apply to the growing, harvesting, processing, and distribution of shellfish for human consumption (U.S. Departent of Health and Human Services 1990). Until recently the NSSP did not recognize pond systems as approved shellfish growing areas. Man-made ponds are not part of the natural, estuarine system. Man-made ponds were not classified and, therefore, not approved for shellfish culture. Producing oysters or clams with the intent to enter commercial market channels for human consumption was viewed as being out of compliance with FDA since ponds and other upland growing areas were not classified within the NSSP.

The ISSC adopted a new aquaculture chapter for the NSSP Manual of Operations at its August 1991 meeting. These requirements will be in effect in early 1992. The chapter places specific requirements on any cultured molluscan shellfish destined for interstate commerce. In general, cultured product must meet all requirements of natural harvests. Some additional requirements for shellfish cultured in upland containment systems during growout are required. Culturists must have a permit and approved operational plan for each facility. Records of sources of shellfish, dates of introduction and harvest, quality of water, and design of water treatment must be maintained. Operating procedures for containment systems must be approved by the state shellfish control agency. These procedures must include a description of the water system, source and species or organisms, means of ensuring that contamination by poisonous and deleterious substances will be prevented, monitoring of quality of shellfish food, and monitoring of the quality of the water and harvested shellfish. Water quality must be monitored the same as any natural growing area except that those systems wherein water does not meet approved growing area criteria, as defined by the NSSP, at all times must be monitored more frequently immediately before shellfish are harvested. If the water quality does not meet these criteria for the last 14 days before harvest or if the molluscan shellfish are cultured along with any non-molluscan species, the shellfish must be relayed or subjected to controlled purification before marketing. These regulations, in total, are designed to mirror requirements for natural

grow out and harvest except where the quality of source water is questionable or marginal, or where polyculture occurs. Potential investors should be cautioned that the FDA will closely scrutinize, under the auspices of the NSSP, any operation where molluscs are being produced for human consumption.

The oyster and clam aquaculture industry will likely benefit from working closely with the FDA and the ISSC in developing and complying with the appropriate water quality standards for upland culture of molluscs. Potential investors in containment area bivalve culture will need to become aware of the new regulations and criteria which now apply to aquaculture production of molluscs.

Summary

Technological innovations in the culture of hard clams and oysters have generated increased interest in commercial investment for the southeastern region of the United States. Recent research efforts have assessed the financial performance of the various hatchery, nursery, and growout methods for hard clams, and to a lesser extent, oysters. The findings indicate that substantial profits can be realized for hard clam nursery and growout, and oyster growout operations, under a set of favorable assumptions. These findings apply to shoreside and open-water settings.

No empirical data exists for hard clam or oyster culture in a containment area pond setting. However, certain implications of imposing the containment area pond environment on shoreside/open-water technologies can be qualitatively assessed. In terms of disadvantages, containment area ponds will require considerable investment in water movement systems to ensure oxygen, temperature, salinity, and algal food supply requirements are met. Siltation, which could result from periodic spoil disposal, must be dealt with. In terms of advantages, predation will be minimal, off-bottom culture will not be restricted by public navigational constraints, greater control over temperature and other water quality parameters may allow for increased growth rates, polyculture may be possible, and floating pen nursery systems may be utilized which can operate with minimal water movement costs, as compared to shoreside facilities.

Containment area pond culture of hard clams and oysters must, however, comply with any future water quality standards and criteria imposed by the FDA and the ISSC. For without eventual classification within the NSSP and strict compliance with any future criteria designed for molluscan aquaculture, utilization of containment area ponds for commercial bivalve culture, regardless of the level of technical and economic feasibility, may be in jeopardy.

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Economic Analysis of Production Alternatives for Texas Shrimp Farms

by
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Introduction

The first shrimp farm built in Texas is near Brownsville. It began with large 10 ha ponds and a semi-intensive production technology. There are about 10 shrimp farms in Texas between Freeport and Brownsville on the coast, and inland in the Trans-Pecos area in West Texas. In the short period since shrimp mariculture began in Texas, production techniques have varied in: pond size; aeration levels; quality, quantity, and source of feed; crops per season; use of nursery ponds; stocking density; species; rates of water exchange; and location. Individual farms in production, during 1990, generally were less than 40 surface ha each, with production ponds ranging from less than 1 ha to over 4 ha. Currently, intensive production strategies are used almost exclusively, producing around 3000 kg/ha; however, two farms use a more intensive strategy, producing about 6000 kg/ha.

The objectives of this paper are: 1) to determine the structure of the economies of scale of semi-intensive, intensive, and very-intensive shrimp production alternatives and 2) to compare profitability of these production alternatives.

Methods and Data

Methods

Five farms for each of three production alternatives (semi-intensive, intensive, and very-intensive) are developed (Table 1). The analysis is based on average production data and the economic engineering approach (French 1979). Range of farm sizes are from a one person, or family operated business, to large agribusiness facilities. Biological data and cost estimates were used with MARSIM (Hanson et al. 1985), a firm level simulation model, to generate the annual activities of each shrimp farm. Shrimp farms have 10-yr planning horizon and are analyzed based on total investment, annual operating costs, costs per kg of shrimp produced and internal rate of returns (IRR).

The IRR of an investment is that discount rate at which the net present value (NPV) equals zero. The NPV of an investment is the sum of the present values for each year's net cash flow (to the investor) including ending equity, less the cost of the investment. Operation of the farms are from January 1991 to December 2000. The IRR base point is January 1989 since initial planning and investment began two years prior to operation.

Table 1
Shrimp Farm Size Simulated on the Mid-Texas Coast by Production Alternative

	Total Farm Area, ha	Total Surface Area in Ponds, ha	Number of Ponds
Semi-Intensive	32	20	2
	54	40	4
	114	80	8
	198	160	16
	474	320	32
Intensive	20	10	5
	36	20	10
	59	40	20
	115	80	40
	215	160	80
Very Intensive	18	8	8
	31	16	16
	60	32	32
	112	64	64
	199	128	128

[1] Texas A&M University, College Station, TX.

Data/assumptions

Aggregate data for 1986, 1989, and 1990 were used for the analyses from Texas shrimp farmer's production and operational records. Data by pond includes growth, survival, and harvest biomass and when available, processing yields (percentage) or pounds of tails sold. Processing yield was not provided by all farmers since some market their product heads-on. Management practices information includes: quality of feed (protein content and manufacturer); number of feedings per day; aeration (hp/ha); and water exchange (percentage per day). Table 2 shows these data classified into production alternatives based on pond size, aeration level, and crops produced per year. Only data that fit these classification criteria are averaged to determine the operational and biological parameters for each alternative.

Table 2
Classifying Production Alternative Criteria for Shrimp Farms on the Mid-Texas Coast[1]

Criteria	Semi-Intensive	Intensive	Very Intensive
Pond size, ha	7-15	1.5-4.0	0.5-1.45
Aeration, hp/ha	0	3-12	17-32
Crops/year	1	1	1

[1] Not all ponds can be classified.

Construction cost estimates include: investments for land; pumping equipment (axial-flow pumps, intake box, and electric motors); construction (ponds, canals, buildings, and pumping stations); general equipment; and miscellaneous items (lab supplies, general maintenance equipment, etc.). Owners of recently built farms, suppliers, and contractors quoted prices for these items. Larger farms received financial benefits, such as discounts for repeated procedures and bulk purchases.

Building the farm takes place during a maximum period of two years. Table 3 gives pond dimensions used in each system. Earth moving cost estimates are based on rates charged by regional commercial excavators. Large farms receive advantages in development costs (Yates 1988). Land price varies with the size of the tract bought by the farms; from \$2,717 to \$3,458 /ha. A 15-m boundary is maintained between the property line and the outer pond levee for each farm. Number, arrangement, and pond size influence utilization efficiency of farm surface acreage. To illustrate, the semi-intensive 474-ha farm uses 75 percent of its total land area as actual pond surface, whereas the very-intensive 18-ha farm uses only 47 percent of its total land area in pond surface.

Table 3
Dimensions Used for Calculating Earth Moving Costs for Shrimp Farms on the Mid-Texas Coast by Production Alternative

Category	Production Alternative: Semi-Intensive	Intensive	Very Intensive
Pond Characteristics			
Size, ha	10	2	1
Length, m	450	200	141
Width, m	225	100	71
Depth, w ater in m	1.2	1.2	1.2
Bottom Slope, %	1	1	1
Levee Characteristics			
Crown Width			
Internal, m	3.5	3.5	3.5
External, m	5.0	5.0	5.0
Freeboard			
Internal, m	0.3	0.3	0.3
External, m	0.9	0.9	0.9
Slope			
Internal, m	3:1	3:1	3:1
External, m	2:1	2:1	2:1
Height of Levee	1:5	1:5	1:5

Farms are independent, that is, they share no equipment, land or buildings with other enterprises. A combination shop and office building (ranging from 93 to 279 m) is included on each farm. Each shop has enough hand and power tools to do basic repair and maintenance work. Partial budget analyses were used to determine needed equipment to assure least cost operation.

Cost of labor reflects the time and skill needed to accomplish each task associated with farm operation and include: feeding; water flow management; biological management; mechanics and maintenance; secretarial and accounting; general management; and seasonal. Water flow involves monitoring flow

rates, maintaining pump stations, and cleaning screens. Biological management involves determining feed levels, sampling shrimp, monitoring water quality, and detecting disease. Seasonal management includes repairing and preparing ponds, stocking and harvesting.

Principal differences between the three production alternatives include pond management and operational activities. Feeding occurs once daily, three times daily, and four times daily for semi-intensive, intensive and very-intensive farms, respectively. Intensive and very-intensive ponds have 7.5- and 25-hp/ha aeration, respectively, whereas semi-intensive ponds are not aerated. Daily water exchange rate is equal among systems up to a maximum of 15 percent per day. Pumping and aeration cost $0.07/kwh. Semi-intensive farms use 35 percent protein feed and intensive and very-intensive farms use 40 percent protein. Sacked feed is used on smaller farms and bulk feed in larger farms. Rail transportation of feed is used when bought in enough quantities. Farms using more than 1,000 metric tons of feed annually (about 2 rail cars per week) receive a $0.025/kg discount. Feed costs decreased from $660 to $600 per ton (small to large farms, respectively) for semi-intensive alternatives and $763 to $703 for intensive and very-intensive farms.

Repair costs are 3 percent of purchase price of machinery and pond for the first three years and 5 percent after that. Property taxes are $12.35/ha and post larvae (PL) cost is $9.00/1000. Biological parameters are equal for farms within the same production alternative (Table 4). These biological parameters are averages of shrimp in ponds which matched established management criteria in Table 1.

Since many shrimp farms are Subchapter S corporations or partnerships, this analysis is on a pre-income tax basis. Depreciation of equipment and construction is based on useful life. Equipment has a fast deterioration in a salt environment and, therefore, depreciates on a fast schedule. Replacement of equipment is based on its salvage value and useful life. Building and pond construction depreciates over 20 and 15 years, respectively.

Table 4
Production Parameters Based on 1989-1990 Production Data from Shrimp Farms Located on the Texas Coast

	Production Strategy		
Category	Semi-Intensive	Intensive	Very Intensive
Fertilization, kg/ha	56	56	56
Stocking density, ha	150,670	395,200	815,100
Date stocked	4/16-5/12	4/16-5/12	4/16-5/12
Date harvested	12/2-10/29	10/2-10/29	10/2-10/29
Days in pond	175	175	175
Feed protein content, %	35	40	40
Feedings/day	1	3	4
Feed conversion	2.80:1	2.31:1	3.15:1
Size stocked	PL5[1]	PL5	PL5
Size harvested, g	22.81	21.81	21.79
Growth from PL, g/wk	0.85	0.85	0.85
Survival, %	45	41	38
Approximate production heads on, kg/ha	1,650	3,560	6,803
Processing yield, %	65	65	65
Aeration , Hp/ha	0	7.5	25
Maximum water exchange, %/day	15	15	15

[1] PL5 indicates a substage 5 postlarvae.

This analysis excludes the effects of inflation and all prices are constant 1991 dollars. All farms are constructed with 100 percent equity financed; however, operating loans are used during the production season.

Prices received for the shrimp are based on historical Western Gulf prices from 1981 to 1990. An extrapolated price pattern reveals a 3-yr cycle of prices, with the lows beginning in 1990. A 5 percent premium is commanded by farmed shrimp (*P. vannamei*) based on uniformity and quality. Harvested shrimp are distributed into size classes based on the 1989 *P. vannamei* harvest of a Texas coastal farm. Processing yield average for the 1989 and 1990 Texas harvests is 0.65.

Results

Investment

The most important investment categories are land and pond construction for semi-intensive farm (Table 5). Economies of scale, reflected in the costs per hectare, decrease from $18,478/surface ha for the 2-pond farm to $9,664 for the 32-pond farm, a reduction of about 48 percent. Pond construction is the intensive farms' largest cost reflecting the large investment in aerators. Economics of scale shows a decrease from $42,343/ha for the 5-pond farm to $19,257 for the 80-pond farm (decrease of about 55 percent). Construction and equipment, which account for more than 50 percent of investment, are the most important cost categories for the very-intensive farms. Economies of scale are represented by investments per surface hectare decrease from $68,340 to $31,707, or 54 percent.

Land and pumping facilities decreases in importance with intensification whereas pond equipment increases in importance. The importance of pond construction and buildings are stable across levels of intensity.

Annual cost of production

Comparing Tables 5 and 6, in general, reveals the more intensive and larger the farm the more important annual operating cost is relative to investment cost. To illustrate, annual operating cost (less depreciation) as a percent of investment cost is 43 percent for the 5-pond intensive farm and 96 percent for the 128-pond very-intensive farm. Thus, potential investors should not under estimate the need for operating capital. Notice also, the smallest very-intensive farm has the highest annual cost per surface ha (almost $42,000) whereas the largest semi-intensive production strategy has the least annual cost per surface ha (just over $7,000). Feed cost ranks first in importance among all three production alternatives (Table 7). Ranking second is "Other" costs (ice, fertilizer, repairs, and fixed administration cost) for the semi-intensive and intensive production alternatives, except for the largest farms where stocking cost ranks second. The least important cost is energy for the three production alternatives (except for the two largest very-intensive farms where labor is least important). Very-intensive farms have the highest cost per kg for all levels of production while semi-intensive farms have the lowest cost of production.

Cost categories show different economies of scale. Stocking cost exhibits constant economies of scale except for the semi-intensive production alternatives. Diseconomy occurs because smaller semi-intensive farms allow shrimp to grow a week or two longer since they have fewer ponds and more labor per pond. They stock fewer PLs and produce larger shrimp. Energy has constant economies of scale in the intensive or very-intensive strategies. Some economies of scale are available for feed due to bulk, volume discount, and rail transportation costs. Most economies of scale are accounted for by labor, depreciation and "other" costs. Economies of scale are approximately 22 percent for all three production alternatives.

Internal rate of return

Figure 1 is used to compare the investments in these three farms alternatives. For an investment less than one million dollars, the semi-intensive production alternative has the highest IRR. However, the intensive production alternative has the highest IRR for investments greater than one million dollars. Comparing returns by level of investment is the proper method of economic analysis; however, farms may face constraints other than capital. Land available for shrimp farms may be limited as it is in some states and countries. The returns of the three production alternatives are compared, based on total farm area in Figure 2. In this case, the very-intensive method of production appears to be most attractive. Intensive production alternatives are almost as attractive as very-intensive systems whereas semi-intensive farms are considerably less attractive when land constraints are imposed.

Table 5
Investments in Shrimp Farms on the Mid-Texas Coast 1991 U.S. Dollars ($); (may not add due to rounding)

Number of Ponds	Total Land, ha	Land Total		Pond Equipment		Pond Construction		Buildings		Pumping Facilities		Other		Total		Total/ Surface Acre, ha
Semi-Intensive																
2	31.0	109,200	(0.30)	19,360	(0.05)	90,732	(0.25)	26,070	(0.07)	79,200	(0.21)	45,004	(0.12)	369,566	(1.00)	18,478
4	53.2	186,200	(0.31)	55,660	(0.09)	140,261	(0.23)	26,070	(0.04)	130,900	(0.22)	63,759	(0.11)	602,850	(1.00)	15,071
8	112.4	393,400	(0.37)	99,550	(0.09)	247,663	(0.23)	26,620	(0.03)	162,800	(0.15)	133,393	(0.13)	1,063,426	(1.00)	13,293
16	195.2	634,400	(0.36)	145,200	(0.08)	479,846	(0.27)	34,980	(0.02)	260,700	(0.15)	202,422	(0.12)	1,757,548	(1.00)	10,985
32	428.4	1,178,100	(0.38)	198,880	(0.06)	1,025,955	(0.33)	37,840	(0.01)	401,500	(0.15)	250,298	(0.08)	3,092,493	(1.00)	9,664
Intensive																
5	19.2	67,200	(0.16)	98,670	(0.23)	102,504	(0.24)	27,390	(0.06)	69,691	(0.16)	57,976	(0.14)	423,431	(1.00)	42,343
10	34.8	121,800	(0.19)	128,920	(0.21)	166,632	(0.27)	32,780	(0.05)	85,091	(0.14)	92,578	(0.15)	627,801	(1.00)	31,390
20	58.0	203,000	(0.21)	207,240	(0.21)	273,009	(0.28)	29,260	(0.03)	122,650	(0.12)	153,845	(0.16)	989,004	(1.00)	24,725
40	112.8	394,800	(0.23)	369,270	(0.22)	540,219	(0.32)	34,705	(0.02)	162,800	(0.10)	184,811	(0.11)	1,686,605	(1.00)	21,083
80	212.4	690,300	(0.22)	716,430	(0.23)	1,058,552	(0.23)	45,760	(0.01)	337,700	(0.11)	232,433	(0.08)	3,081,175	(1.00)	19,257
Very-Intensive																
8	17.2	59,500	(0.11)	132,506	(0.24)	177,126	(0.32)	28,574	(0.05)	57,585	(0.11)	91,431	(0.17)	546,722	(1.00)	68,340
16	30.4	105,000	(0.13)	210,276	(0.27)	249,613	(0.32)	26,598	(0.03)	81,785	(0.10)	117,392	(0.15)	790,664	(1.00)	49,417
32	59.1	204,400	(0.15)	361,103	(0.27)	414,362	(0.31)	34,276	(0.03)	122,650	(0.09)	194,286	(0.15)	1,331,077	(1.00)	41,596
64	104.0	359,800	(0.16)	646,470	(0.28)	720,044	(0.31)	41,833	(0.02)	162,800	(0.07)	385,321	(0.17)	2,316,268	(1.00)	36,192
128	198.8	638,300	(0.16)	1,186,790	(0.29)	1,413,550	(0.35)	48,345	(0.01)	260,700	(0.06)	510,854	(0.13)	4,058,539	(1.00)	31,707

Table 6
Annual Costs for Shrimp Farms on the Mid-Texas Coast (U.S. Dollars ($); may not add due to rounding)

Number of Ponds	Stocking	Feed	Labor	Energy	Depreciation	Other	Total	Total/Surface Acre, ha
Semi-Intensive								
2	27,450	60,708	31,710	16,219	24,487	48,147	184,234	9,212
4	54,900	121,413	55,015	32,438	38,638	80,294	344,060	8,602
8	115,200	231,617	97,640	62,704	56,827	131,451	638,612	7,983
16	230,400	446,465	169,029	118,229	101,749	235,932	1,200,055	7,500
32	4,602,800	861,322	282,513	236,458	165,400	414,748	2,255,841	7,050
Intensive								
5	36,000	63,010	35,000	14,137	32,087	63,960	212,107	21,211
10	72,000	125,896	67,945	28,134	41,742	91,071	385,046	19,252
20	144,000	240,183	125,594	56,265	68,292	151,394	717,436	17,936
40	288,000	478,914	215,500	112,534	111,291	259,390	1,354,338	16,929
80	576,000	928,803	375,000	225,069	211,334	489,753	2,594,625	16,216
Very-Intensive								
8	59,400	131,270	34,291	22,735	47,011	39,221	333,928	41,741
16	118,800	258,757	48,630	45,469	66,369	62,392	600,417	37,526
32	237,600	499,356	99,660	90,938	106,722	107,482	1,141,758	35,680
64	475,200	968,448	178,819	181,841	178,461	194,319	2,177,088	34,017
128	950,400	1,933,869	303,639	363,751	303,726	362,048	4,217,435	32,949

Table 7
Annual Costs per kg (%) for Shrimp farms on the Mid-Texas Coast (U.S. Dollars ($); may not add due to rounding)

Number of Ponds	Stocking		Feed		Labor		Energy		Depreciation		Other		Total		Total/Surface Area, ha
Semi-Intensive															
2	1.28	(0.15)	2.84	(0.33)	1.48	(0.17)	0.76	(0.09)	1.14	(0.13)	2.25	(0.26)	8.61	(1.00)	47,069
4	1.28	(0.16)	2.84	(0.35)	1.29	(0.16)	0.76	(0.09)	0.90	(0.11)	1.88	(0.23)	8.04	(1.00)	94,139
8	1.34	(0.18)	2.69	(0.36)	1.13	(0.15)	0.73	(0.10)	0.66	(0.09)	1.52	(0.21)	7.41	(1.00)	189,704
16	1.38	(0.19)	2.67	(0.37)	1.01	(0.14)	0.71	(0.10)	0.61	(0.08)	1.41	(0.20)	7.18	(1.00)	367,615
32	1.38	(0.20)	2.58	(0.38)	0.85	(0.13)	0.71	(0.10)	0.49	(0.07)	1.24	(0.18)	6.75	(1.00)	735,231
Intensive															
5	1.55	(0.17)	2.71	(0.30)	1.50	(0.17)	0.61	(0.07)	1.38	(0.15)	2.75	(0.30)	9.11	(1.00)	51,198
10	1.55	(0.19)	2.71	(0.33)	1.46	(0.18)	0.61	(0.07)	0.90	(0.11)	1.96	(0.24)	8.28	(1.00)	102,295
20	1.55	(0.20)	2.58	(0.33)	1.35	(0.18)	0.61	(0.08)	0.73	(0.10)	1.63	(0.21)	7.71	(1.00)	204,590
40	1.55	(0.21)	2.57	(0.35)	1.16	(0.16)	0.61	(0.08)	0.60	(0.08)	1.39	(0.19)	7.28	(1.00)	409,180
80	1.55	(0.22)	2.50	(0.36)	1.01	(0.14)	0.61	(0.09)	0.57	(0.08)	1.32	(0.19)	6.98	(1.00)	818,361
Very Intensive															
8	1.67	(0.18)	3.69	(0.39)	0.96	(0.10)	0.64	(0.07)	1.32	(0.14)	1.10	(0.12)	9.39	(1.00)	78,218
16	1.67	(0.20)	3.64	(0.43)	0.68	(0.08)	0.64	(0.08)	0.93	(0.11)	0.88	(0.10)	8.44	(1.00)	156,437
32	1.67	(0.21)	3.51	(0.44)	0.70	(0.09)	0.64	(0.08)	0.75	(0.09)	0.76	(0.09)	8.03	(1.00)	312,873
64	1.67	(0.22)	3.40	(0.44)	0.63	(0.08)	0.64	(0.08)	0.63	(0.08)	0.68	(0.09)	7.65	(1.00)	625,746
128	1.67	(0.23)	3.40	(0.46)	0.53	(0.07)	0.64	(0.09)	0.53	(0.07)	0.64	(0.09)	7.41	(1.00)	1,251,493

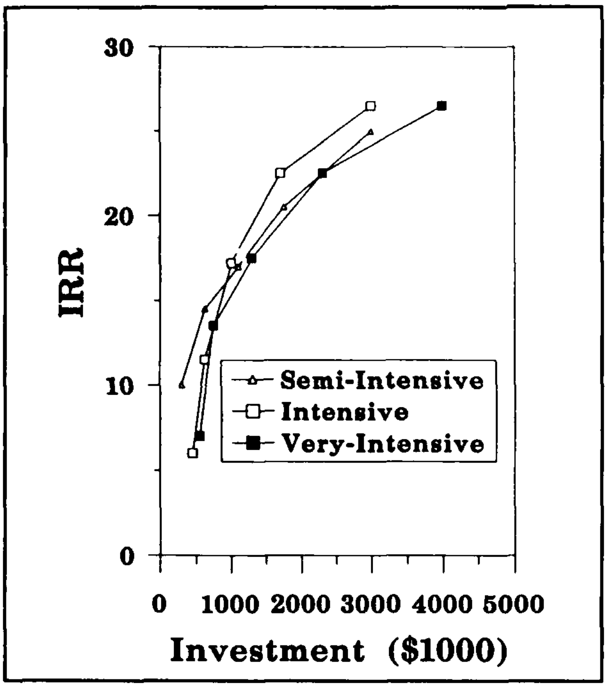

Figure 1. IRR for shrimp farms on the mid-Texas coast

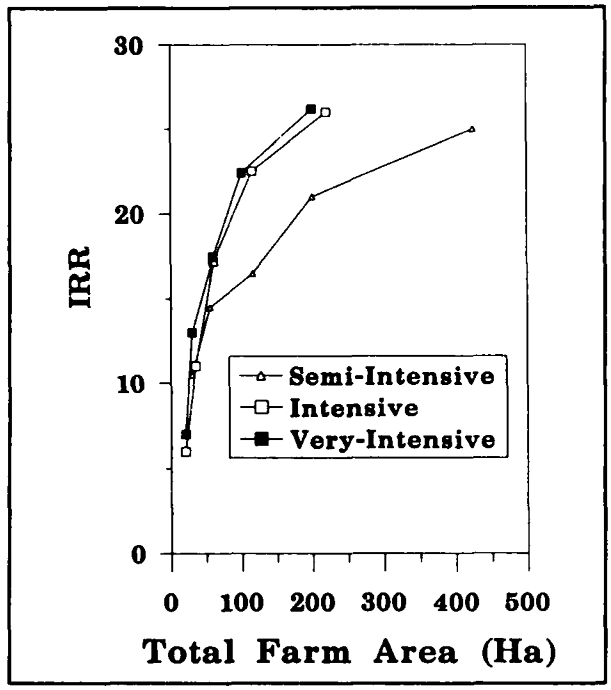

Figure 2. IRR by total land area of shrimp farms on the mid-Texas coast by production strategy and farm size, 1991

Conclusions

Large economies of scale are associated with each production alternative and these economies are approximately the same magnitude. Per pond surface area investment decreases approximately 50 percent from the smallest to the largest farm, while annual production costs decrease about 22 percent. The semi-intensive alternative is clearly a better choice when investment is less than one million dollars; however, the intensive strategy does provide slightly higher net returns when investment exceeds one million dollars. Several conclusions can be drawn from this study:

- The individual investor's constraints of capital, land, water, and management skill should determine the choice of production alternative since these constraints will ultimately determine the success of the business.
- Current farm production values, investment, and annual cost indicate the movement toward more intense production strategies cannot be economically justified except where land is the limiting factor.
- When one is selecting a management alternative, annual costs should be examined closely since annual costs are 43 to 96 percent of investment costs. A study by Klinefelter (1988) indicates that producers overestimated cash receipts by 15 percent and underestimated cash expenditures by 17 percent. Being overly optimistic when reporting to a loan office is one matter, but failure to have accurate estimates for internal use can result in: not producing; selling shares of the company to have operating capital; harvesting the crop prematurely to meet debt obligations; and or bankruptcy (Chapter 13).
- Since feed is the largest expense item, the price and availability of quality feeds should be of concern to producers and industry promoters. Economies of scale observed by larger farms especially by ordering in bulk could be gained by small producers through the development of cooperative buying arrangements. Food

conversion ratio improvements would increase net returns to investors.

- Since post larvae are the second largest annual cost for most farms, the more intense the production system the greater would be the relative effect of survival on IRR.

- Since energy is a minor part of annual costs, it is strongly suggested that the trade-off between aeration level and biological performance receive close attention by the industry and researchers.

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Crawfish Farming: An Economic View

by
Robert S. Pomeroy[1]

Introduction

Crawfish are found growing naturally in practically every body of water in the United States from roadside ditches to swamps. However, most "wild" crawfish caught commercially in this country are harvested from the Atchafalaya Basin of Louisiana. Production is estimated to range from 5,000-25,000 metric tons (MT) per year and is dependent upon the vagaries of nature.

Crawfish are also cultured commercially, primarily in the Southeastern region of the United States. The commercially exploited species dominant in the United States are the red swamp crawfish (*Procambarus clarkii*) and the white river crawfish (*Procambarus acutus acutus*). These two species alone account for more than 95 percent of the United States commercial harvest. The commercial culture of crawfish also occurs in the North central region (primarily *P. clarkii* and *P. acutus acutus*) and Northeastern region (primarily *Orconectes* spp.) of the United States. While Louisiana is the leading cultured crawfish production state in terms of pond area and production, other producing states, in order of decreasing pond area, are Texas, Florida, South Carolina, Arkansas, Mississippi, and Georgia (Table 1).

Louisiana has ideal conditions for crawfish production including low, flat, poorly drained lands well-suited for aquaculture and extensive areas of rice cultivation that are easily converted to crawfish production either in a crop rotation with rice, soybeans, and/or grain sorghum or in monoculture depending on the economics at the time. Southeastern Texas is ecologically similar to southwestern Louisiana, a major crawfish and rice production region. Therefore, it is not surprising that Texas is the second leading state in crawfish production.

Table 1
Cultivation of *Procambarus* spp. in the United States[1]

State	Estimated Pond Area, ha, 1988
Louisiana	56,580
Texas	7,300
Arkansas	200
Mississippi	100
Alabama	<50
Florida	800
Georgia	<100
South Carolina	445
North Carolina	<50
Maryland	<50

[1] These are "good faith" estimates based on conversations with commercial and governmental sources in all states involved. Those from Louisiana and Texas are most accurate. The other estimates may vary as much as 10 from the stated values. Furthermore, some production is present in some "cultivated" ponds in most states at lower latitudes but statistics, real or estimated are not available.

The cultured crawfish industry began its development in South Louisiana in the early 1960s and has had phenomenal growth in the last three decades. Cultivation technology and intensity used in cambarid crawfish cultivation is low compared to many other cultured species such as channel catfish and marine shrimp. Self-sustaining populations of crawfish are typically established in low-cost earthen ponds. Water circulation is needed during warmer months. However, the remaining needs of crawfish are minimal. They do not need hatcheries. They do not need expensive feed. They do not need deep water (18 in. is sufficient). Water-tolerant plants, such as rice and alligator weed, are typical forages and can be grown in the pond. In addition,

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crawfish eat worms, insect larvae, and other animal matter.

Commercial Crawfish Cultivation Practices

Site selection and pond construction are important in successful crawfish aquaculture (de la Bretonne and Romaire 1989). Open ponds, which account for 65-70 percent of the production area in Louisiana and 100 percent in other states, range from 2.5 to 250 acres in size. However, most ponds cover 20 to 40 acres. Crawfish yield from ricefield crawfish ponds is generally 900 to 1,000 lb per acre, with better managed ponds routinely producing 1,280- to 2,000-lb per acre. Crawfish are commonly double-cropped with rice in Louisiana and Texas.

Permanent crawfish ponds are those constructed solely for the purpose of cultivating crawfish. Crawfish can be harvested in permanent ponds 1 or 2 months longer because there is no conflict with planting, draining and harvest schedules of other crops. Crawfish yield from permanent, open ponds is generally 10-30 percent higher than ricefield ponds in which rice and crawfish are double cropped.

Crawfish ponds should be located in flat, open areas and the soils should have sufficient clay to hold water. Clay loams, sandy clay, sandy clay loam, and silty clay loams are satisfactory. Sandy soils are not conducive to crawfish production. Perimeter levees should have a core trench filled with clay to prevent water seepage, and the minimum perimeter levee base should be 10-ft wide to prevent leakage from burrowing activities of crawfish. Interior circulation levees are constructed to provide for an adequate flow of water within the pond. Water-control structures are installed to provide water management capability including water depth, water circulation, and water removal (drainage) at the end of the production cycle. This includes a riser, PVC pipe, anti-seepage collar and other miscellaneous hardware.

Water quantity and quality are the most common limiting factors in crawfish aquaculture. A pumping capacity of 100-gal per minute per acre is needed to exchange water 24-in. deep in 3.5 days. This exchange rate is essential to maintain satisfactory water quality in the fall and late spring when water temperature is highest. Both subsurface and surface water are acceptable for crawfish cultivation. Mechanical paddlewheel aerators can be used to aerate and circulate water in crawfish ponds more cost effectively than water replacement.

Crawfish are amenable to culture because they are hardy, the life cycle can be easily manipulated to fit a variety of cultural situations, and they can be easily integrated into agricultural crop rotations. The culture cycle for crawfish in permanent ponds is as follows. The ponds are flooded and stocked in April-May of the first year at the rate of 75 lb per acre. Ponds are restocked every fourth year with 50 percent new broodstock to maintain genetic diversity. In late spring or early summer, the ponds are slowly drained over a 2- to 4-week period to simulate the summer drying of natural habitat of crawfish. During this time the crawfish burrow and reproduce. Rice, sorghum, or other vegetation is planted during this dry period to serve as crawfish forage. Pond and levee maintenance is conducted during this period. In late September and early October, the pond is reflooded once the burrows have been checked to observe the condition of eggs and hatched young crawfish. Depending upon the location, crawfish are harvested from November through May or June. The primary harvest season is February to June. Baited wire traps are used for trapping. These traps are run daily. Artificial crawfish bait is used in each trap. In May or June, the pond is drained and the cycle is repeated. While supplemental feed is normally not used in the crawfish production cycle, research is currently underway to use supplemental feed to extend the harvest season, increase growth and production, and minimize stunting of crawfish when vegetation is depleted.

A variety of different harvesting devices are available ranging from (a) walking while pulling a small boat, to (b) a flat-bottomed boat, "Go-Devil" design, to (c) a modified "crawfish combine" design. The proper harvesting device will depend on each individual crawfish operation. Harvested crawfish are held in a holding tank/purge system for several hours before being placed in ventilated mesh bags or sacks for transport.

As mentioned, there are several alternative crawfish-agronomic crop rotations including rice-crawfish-rice, rice-crawfish-soybeans, and crawfish-rice set-aside (de la Bretonne and Romaire 1989). While potentially providing more income per acre as a result of double- or triple-cropping, problems include pesticide use, poor water circulation, and shorter harvest season. In addition to crawfish-agronomic crop rotations, crawfish/waterfowl double-crop systems can provide income from both the lease of hunting rights and the harvest of crawfish. These systems are managed with the primary purpose of attracting waterfowl and the secondary purpose of cultivating crawfish. As practiced in South Carolina, for example, the crawfish/waterfowl systems are almost exclusively located along major coastal river systems in former ricefields (Eversole and Pomeroy 1989).

Crawfish Marketing

Crawfish markets and prices are very geographic and product form specific. Marketing crawfish requires planning and, depending upon location, may require more sales effort than other aquaculture species. Two markets exist for crawfish: the food market and the fish bait market.

Crawfish are sold either live or processed. Consumption of whole, live crawfish is about 50 percent of annual production nationwide (Moody 1989). Local markets, mostly households, retail markets, and restaurants are the major purchasers of whole, live crawfish for boiling. Live crawfish are also shipped by air to national and international markets. Processed product forms include whole, raw and frozen crawfish; whole, cooked and frozen crawfish; cooked, peeled and deveined crawfish meat; and further processed such as bisque and etouffe. A new product is soft-shell crawfish. The soft-shell crawfish is harvested when the crawfish molts. The processed product is packaged in various forms to meet national and international market requirements. Crawfish yields approximately 16 percent of body weight, while soft-shell crawfish yields approximately 90 percent of body weight. The grading of crawfish has become standard in the industry for both live and processed product.

Domestically, the major crawfish markets are located in the East South Central (Mississippi and Alabama), West South Central (Louisiana, Texas, and Arkansas), and Pacific (California, Oregon, and Washington) regions (Pereira and Dellenbarger 1989). Strong potential markets exist in the Middle Atlantic and South Atlantic regions of the United States. Approximately 50 percent of the production in the major crawfish producing states is sold in-state and the rest to national and international markets. A decline in the supply of crawfish from Turkey opened markets in Europe, primarily France and Sweden, for U.S. crawfish. The export market is also a significant buyer of soft-shell crawfish.

The price of crawfish products can fluctuate greatly during the year. Because crawfish supplies are shorter north of Louisiana, prices are higher. Early season crawfish usually bring higher prices. The producer price of live cultivated crawfish, for example, can range from $0.50 per lb in Louisiana to over $2.00 per lb in Maryland during the harvest season. A good wild harvest season from the Atchafalaya Basin can drop live crawfish prices in Louisiana to as low as $0.25 per lb.

Small crawfish, between 2- and 3-in. long, are used by eastern and Mid-western fishermen. Both hard-shell and soft-shell crawfish can be sold as fish bait.

Very little formal market information exists on the crawfish industry. No state or Federal agency currently formally collects data

on crawfish supply and price. A crawfish producer's and buyer's best market information is that which is available from industry sources such as associations, producers, processors, retailers, and research and extension specialists.

Economics of Crawfish Production

Estimated investment requirements, production costs, and breakeven prices for crawfish production have been prepared for South Carolina (Pomeroy, Whetstone, and Luke 1989) and Louisiana (Dellenbarger, Vandeveer, and Clarke 1987). These enterprise budget and cash flow statement estimates are based on permanent crawfish pond production system described above.

The enterprise budgets for crawfish prepared for South Carolina represent five operation sizes of 5, 10, 20, 40 (two 20-acre ponds), and 80 (four 20-acre ponds) (Tables 2, 3, and 4). The ponds are upland, embankment-type that are rectangular and use well water.

The establishment year budget reflects costs and returns during the first year of operation when yields are normally low at 400 lb per acre. The full production year budget reflects costs and returns during subsequent years when yields are 900 lb per acre. A producer/farm gate price of $1.25 per lb is used in the analysis.

The estimated total capital investment cost for a 20-acre pond system is $24,385, which includes cost of pond construction, water pumping system (excluding well cost), harvest boat, and other equipment. It does not include the cost of land purchase (Table 1).

An enterprise budget for the full production year is presented in Table 2. Pumping and repair and maintenance are the major preharvest

Table 2
Crawfish Operation Construction and Capital Cost

	Years of Life	Five-Acre	Ten-Acre	Twenty-Acre	Two Twenty-Acre	Four Twenty-Acre
Pond construction:						
Site clearing $50/acre	25	250	500	1,000	2,000	4,000
Construct primary levees	25	3,960	5,604	7,920	12,860	23,760
Construct secondary levees	25	—	—	—	1,050	3,960
Circulation levees $.50/linear ft.	25	250	600	1,200	2,400	4,800
Vegetation cover $11.40/acre	25	55	115	230	460	915
Water control (drainage pipes)	25	250	500	750	1,500	3,000
Subtotal pond construction		**4,765**	**7,319**	**11,100**	**20,270**	**40,435**
Water pumping system:						
Delivery pump	15	1,350	1,540	2,020	4,040	8,080
Starting equipment	15	300	400	—	—	—
Phase converter	15	—	—	2,280	4,560	9,120
Pipes and fittings	15	900	2,000	4,000	8,000	16,000
Installation	15	300	400	600	1,200	2,400
Subtotal water pumping system		**2,850**	**4,340**	**8,900**	**17,800**	**35,600**
Holding tank and pump	15	300	500	800	1,500	1,700
Service bldg. and pad for pump	15	300	380	450	800	1,000
Scale	15	125	125	125	125	250
Harvest systems:						
Crawfish combine	15	—	—	—	4,500	4,500
Boat	15	600	—	—	—	—
Go-Devil boat	15	—	2,500	2,500	—	—
Splash board	15	75	75	75	300	300
Purge system	15	45	90	135	270	540
Miscellaneous	15	200	250	300	400	450
Total		**9,260**	**15,579**	**24,385**	**45,965**	**84,775**

Note: If trees are present, site clearance cost will be substantially increased; assume well exists.

Table 3
Crawfish for Human Consumption

	Units	Price or Cost/Unit	Quantity	Value or Cost for 20 Acres	Value or Cost per lb	Value or cost per Acre	Your Estimates
Gross receipts—crawfish: Twenty-acre pond	lb	$1.25	18,000	$22,500.00	$1.25	$1,125.00	—
Variable costs							
Preharvest:							
Land cultivation	Acre	$18.00	20	$360.00	$ 0.02	$18.00	—
Rice seed	CWT	16.00	20	320.00	0.02	16.00	—
Fertilizer	CWT	8.50	40	340.00	0.02	17.00	—
Lime (spread)	Tons	26.00	20	520.00	0.03	26.00	—
Repair and maintenance	Acre	63.00	20	1,260.00	0.07	63.00	—
Mowing	Acre	8.00	20	160.00	0.01	8.00	—
Breeding stock	Lb.	1.33	0	0.00	0.00	0.00	—
Pumping	Acre	46.00	20	920.00	0.05	46.00	—
Transportation	Acre	20.00	20	400.00	0.02	20.00	—
Insurance & taxes	Acre	6.50	20	130.00	0.01	6.50	—
Miscellaneous	Acre	0.00	0	0.00	0.00	0.00	—
Family Labor	Hr.	0.00	175	0.00	0.00	0.00	—
Hired Labor	Hr.	4.25	0	0.00	0.00	0.00	—
Interest on op cap	Dollar	11%	$4,410.	206.17	0.01	10.31	—
Subtotal, Preharvest				4,616.17	0.26	230.81	—
Harvest Costs:							
Boxes and Sacks	Each	0.65	360	234.00	0.01	11.70	—
Bait	Lb.	0.17	18,750	3,187.50	0.18	159.38	—
Traps (pro-rated)	Acre	50.00	20	1,000.00	0.06	50.00	—
Harvest fuel	Acre	11.00	20	220.00	0.01	11.00	—
Harvest labor	Hour	4.25	600	2,550.00	0.14	127.50	—
Miscellaneous	Unit	0.00	0	0.00	0.00	0.00	—
Subtotal, Harvest				**7,191.50**	**0.40**	**359.58**	—
Total Variable Cost				**11,807.67**	**0.66**	**590.38**	—
Income above variable cost				$10,692.33	0.59	534.62	—
Fixed costs:							
Tractor and machinery	Acre	15.00	20	300.00	0.02	15.00	—
Pond and equipment	Total	2,768.00	1	2,768.38	0.15	138.42	—
Total Fixed Cost				**3,068.38**	**0.17**	**153.42**	—
Total of variable and fixed costs				**14,876.05**	**0.83**	**743.80**	—
Net returns to land, overhead, risk, management and family labor				**7,623.95**	**0.42**	**381.20**	—
Other costs:							
Land charge	Acre	20.00	20	400.00	0.02	20.00	—
General farm overhead	% var.	8.0%	11,808	944.60	0.05	47.23	—
Total Costs				**16,220.66**	**0.90**	**811.03**	—
Returns to management, risk, and family labor				6,279.34	0.35	313.97	—
Breakeven yield cash	**9,446 lb**			**Breakeven price cash**	**$0.66**		
Breakeven yield all costs	**12,977 lb**			**Breakeven price all costs**	**$0.90**		

Income above Variable Costs at Different Prices Yield Levels

	Price				
Yield	**$0.75**	**$1.00**	**$1.25**	**$1.50**	**$1.75**
16,000	911	4,991	8,991	12,991	16,991
17,000	1,342	5,592	9,842	14,092	18,342
18,000	1,692	6,192	10,692	15,192	19,692
19,000	2,043	6,793	11,543	16,293	21,043
20,000	2,393	7,393	12,393	17,393	22,393

Note: Assumes constant preharvest cost and a harvest cost that changes with yield.

Table 4
Comparative Summary of Estimated Costs and Returns for Crawfish Production, South Carolina, 1988

		Gross Receipts	Variable Costs	Total Costs	Returns to Mgt., Risk, and Family Labor	Breakeven Price Cash/All
Five acre	Establishment period	2,500.00	2,626.44	4,048.16	(1,548.16)	—
	Full production year	5,625.00	2,314.42	3,711.18	1,913.82	0.51/0.79
Ten acre	Establishment period	5,000.00	5,302.87	7,839.69	(2,839.69)	—
	Full production year	11,250.00	4,628.83	7,111.73	4,138.27	0.51/0.79
Twenty acre	Establishment period	10,000.00	11,625.74	16,024.18	(6,024.18)	—
	Full production year	22,500.00	11,807.67	16,220.66	6,279.34	0.66/0.90
Forty acre	Establishment period	20,000.00	23,707.65	32,240.00	(23,583.66)	—
(2 20-acre)	Full production year	45,000.00	24,060.20	32,620.76	12,379.24	0.67/0.91
Eighty acre	Establishment period	40,000.00	47,415.31	63,583.66	(23,583.66)	—
(4 20-acre)	Full production year	90,000.00	48,120.41	64,345.17	25,654.83	0.67/0.89

Assumptions: Upland pond, land is owned.
Establishment period – 400 lb per acre yield.
Production year – 900 lb per acre yield.
$1.25 per lb price.

operating costs while bait and labor are the major harvest costs. Bait represents 26 percent and harvest labor represents 22 percent of total operating costs. All preharvest labor is assumed to be family labor. Harvest costs represent approximately 62 percent of total operating costs. Broodstock is the major cost during the establishment year. The break-even price-cash (which includes on operating costs) for the 20 acre operation $0.66 per lb and the breakeven price-all (which includes operating and fixed costs) is $0.90 per lb.

All five of the crawfish production systems (5 - 80 acre) were determined to be profitable at current market prices. The break-even price-all for the three larger production systems (20, 40, and 80 acre) averaged $0.90 per lb. Negative returns were obtained with each system during the first year due to low yields as the crawfish became established. Further improvements in production technology and management should reduce production costs and increase returns. Crawfish production does exhibit strong economies of scale, primarily due to the large proportion of fixed costs.

In comparison, the estimated capital investment cost requirement for a 20-acre crawfish operation in Southwest Louisiana is $30,110 (Dellenbarger et al. 1987) (Tables 5 and 6). The major operating costs, as in South Carolina, are bait and labor. The breakeven price-cash for a yield of 900 lb per acre is $0.43 per lb and the breakeven price-all is $0.97 per lb. The operating costs in southwest Louisiana are lower because the reported input costs (e.g., bait, labor, and pumping) are lower than in South Carolina. The breakeven price-all for a 10-, 20-, 40-, and 80-acre crawfish production system in southwest Louisiana with a yield of 900 lb per acre are $1.48, $0.97, $0.73, and $0.61, respectively.

To date, no economic analysis has been conducted on crawfish-waterfowl systems. Dellenbarger et al. (1987) reports that economic efficiencies may be realized from crawfish-rice double-cropping operations. Integration of crawfish production activities with on-going rice production activities would be expected to contribute to the efficiency in the usage of annual hired farm labor. However, it is also

Table 5
Estimated Investment Requirements and Annual Depreciation Charges for a 20-Acre Crawfish Pond, Northeast Louisiana, 1987

Item	Investment	Depreciation
Pond construction		
Dirt moving (7,704 cu yd @ $.60	$4,622	
Water control structures	731	
Ground cover (2.13 acre @ 94.71/acre)	202	
Total pond construction cost	**5,555**	
Equipment		
Stock (50 lb/acre @ .45/lb)	394	$39
Well (100 ft)	5,500	275
Oxygen meter	600	150
Truck (1,500 value after 5 yr)	9,000	1,500
Traps (5.30/trap) (33/acre)	3,096	1,032
Cooler	1,193	239
Scale	95	19
Aerator	424	42
Go-Devil	900	90
Mower	700	233
Waders (2 pr)	224	112
Pump (3,500 gpm)	7,505	500
Engine - gearhead (93-hp diesel)	10,606	707
Total equipment cost	**40,237**	**4,938**
Total	**45,792**	**4,938**

Table 6
Estimated Annual Operating Costs Associated with a 20-Acre Crawfish Pond, Southwest Louisiana, 1987

	Dollars
Variable Costs	788
Forages (45/acre)	899
Fuel - well (1 22 mcf/hr @ 4 25)	664
Repairs & maintenance	1,402
Labor (5/hr)	76
Herbicides	70
Sacks	2,803
Bait (0 16/lb)	6,702
Total Variable Costs	
Fixed Costs	5,493
Depreciation	3,052
Interest (11%)	8,545
Total Fixed Costs	
Total Annual Costs	**15,247**

Estimated Breakeven Prices Associated with a 20-Acre Crawfish Pond, Southwest Louisiana, 1987

Production/acre, lb	700	900	1,100	1,300	1,500
Total production, lb	12,264	15,768	19.272	22 ,776	26,280
Breakeven, cents/lb					
Variable	0.55	0.43	0.35	0.30	0.26
Fixed	0.70	0.54	0.44	0.386	0.33
Total	**1.25**	**0.97**	**0.79**	**0.68**	**0.59**

recognized that crawfish-rice production systems require more planning in developing the proper sequence and timing of production operations which emphasizes the need for intensive management.

CAAP and Crawfish Aquaculture

Crawfish aquaculture and Containment Area Aquaculture Program (CAAP) appear to complement each other. Site selection will require dredged material containment areas (DMCA) to have fresh water and clay soils. While well water is preferred, surface water can be used if it is relatively free of pollutants. Pond size should not exceed 20 acres in size and must retain water at least 16 in. in depth. Inside levees need to be constructed to get maximum water circulation. Provision must be made to drain the pond annually. Provision must also be made for the planting and growing of a forage crop such as rice. Vehicles, such as tractors, must have access and be able to maneuver in the pond. Regulatory requirements (for example, water discharge permits) in each state should be checked before proceeding with an operation.

From an economic standpoint, the cost of producing crawfish should be lower than for existing commercial operations since there will be no pond construction costs. Pond construction costs are approximately 5 percent of the total cost of producing crawfish. Containment areas will need to be constructed to meet the requirements of crawfish aquaculture. Waterfowl/crawfish systems should be possible in many containment areas since they are located near waterfowl habitat. The expansion of crawfish aquaculture with CAAP should provide additional employment opportunities on the farms and in associated agribusinesses.

Since containment areas may be located outside of the major crawfish production areas, they may open new markets for live crawfish. It should also be noted that in certain locations new crawfish producers may be competing with existing crawfish culturists and/or wild harvest. This may effect the price received and the selection of a market outlet.

The crawfish industry has been stagnant in recent years primarily due to market related issues. Crawfish are not harvested year round which makes the expansion of the live market difficult. A considerable wild harvest still exists in Louisiana, making it difficult for crawfish producers to make certain production and marketing decisions. New domestic and international markets need to be developed. In many areas this may require cooperative marketing by producers to meet market quantity demands. There may also be a need to establish a separate market identity for crawfish, which often competes with shrimp in the market place.

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Product and Market Development in the American Catfish Industry

by
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Introduction

The first known commercial sale of farm-raised catfish occurred in 1960 in Arkansas. The first commercial production, processing, and sale of farm-raised catfish was accomplished about the same time by an innovator in Alabama. Soon after these meager beginnings, some individuals in the Delta Area of Mississippi became interested in catfish as an alternative to traditional row crops on heavy, clay soils that occur in relative abundance in the Delta. The first catfish produced commercially in Mississippi were shipped to small processing plants in Arkansas and Alabama because no markets existed at the time in Mississippi.

The first processing plants were usually setup in some kind of existing building or shed, where processing consisted of skinning, heading, and eviscerating by hand. Specialized catfish processing equipment was nonexistent. Most processed fish were sold as whole-dressed, mainly to local restaurants, small fish markets, and individuals.

At that time throughout the south-central region of the United States, wild-caught catfish was a well-known and widely consumed species—particularly among rural people living near the Mississippi River and its tributaries. Fresh, wild-caught catfish was seasonally available in small fish markets and a few widely scattered catfish specialty restaurants usually located near a major river in the region. Thus, there was a limited market already in existence for farm-raised catfish. Strangely enough, however, there was one early consumer resistance to pond-raised catfish in restaurants that had traditionally served wild-caught fish. This was mainly because of the bland taste of farm-raised, grain-fed catfish, as opposed to river taste of wild-caught fish. This early resistance quickly disappeared as consumers had more exposure to farm-raised fish.

As production increased during the decade of the sixties, the need for more processing and marketing increased and eventually became an acute problem by the end of the decade. Several small processing plants were opened and operated successfully in Mississippi, even though processing was still geared to seasonal production and harvesting. Not until about five years later (1974) when sufficient quantities of catfish were harvested and processed on a year-round basis did producers begin referring to themselves as an industry. This year-round availability of fresh or frozen catfish greatly enhanced market potential. Restaurants, for example, could add catfish as a menu item with confidence that supplies would be adequate throughout the year. "Available year-round" had become an important sales pitch for farm-raised catfish.

As commercial processing continued to expand in the early 1970's, processors began to search for more efficient processing methods and equipment. Since equipment designed for catfish processing was nonexistent at that time, equipment used in other food processing industries was adapted. The first high volume, commercial plants were highly labor intensive, having processing lines consisting of band saws for heading, belly-split tables, vacuum powered eviscerators, a mechanical skinner (designed for skinning liver), chill tanks containing ice slurry for quick cooling of whole-dressed fish, and a conveyor for moving the product down the line. All filleting was done

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by hand as were other operations such as sorting and packing. Costs for wages and salaries typically accounted for 60-67 percent of total operating costs (Fuller and Dillard 1984).

By the early 1980's, automation in the form of mechanical filleting machines, automatic sorters, packing equipment, and deboning machines were introduced in the larger processing plants. The catfish industry offered sufficient growth potential so that manufacturers of processing equipment began to take interest and modify existing fish processing machines, or in some cases, design new machines specifically for catfish. Today, some of the larger plants are among the most modern fish processing plants in the world with state-of-the-art primary and further processing technology. A farmer owned cooperative that began operation in 1981 is today not only one of the most modern, but the largest fish-processing plant in North America.

In January 1991, there were 33 catfish processing plants in the United States reporting processing volume and prices to the U.S. Department of Agriculture (USDA). However, most of the total processing capacity is located in Mississippi, where three major processors have one-shift capacity totaling 155 million kg annually. These three plants alone have sufficient capacity to process 90 percent of all commercial processing reported in the United States in 1990. Industry-wide, less than 60 percent of existing processing capacity is being utilized, which not only increases per unit processing and distribution costs, but results in lower wholesale prices. As new processing plants come on line, they attempt to gain market share by lowering wholesale price. In order to protect market share, existing plants are forced to follow suit. This over-investment in processing capacity has placed serious downward pressure on average wholesale prices and on processing margins.

The topic of this paper is product and market development. While product and market development usually proceed simultaneously with a new and expanding industry, they will be discussed separately. In the following discussion, market development is defined as an increase in the size of the market (increase in value of the product sold) where product development is defined as the introduction of new (further processed) products from catfish.

Market Development

The first small scale processors of farm-raised catfish marketed their product primarily through existing market channels which historically handled limited quantities of wild-caught catfish. These markets consisted of small fish markets usually located along major rivers and lakes, fish peddlers, catfish specialty restaurants, and to a lesser extent, local grocery stores.

It is believed that early efforts by processors to expand the market for catfish involved mostly advertising of specials in local newspapers. Retailers were offered discounts on wholesale price in return for featuring catfish. Processors depended largely on their sales staff and food brokers to promote their product. It is not known when the first brokers were recruited for handling catfish; however, by 1980, approximately 60 percent of sales were arranged by brokers (Miller et al. 1981). Thus, the use of food brokers played an important role in the rapid market expansion that occurred during the last decade (Table 1).

Table 1
Quantity of Processed Farm-Raised Catfish Sold by Commercial Processors, Selected Years, United States

Year	Quantity Sold, 1,000 kg	Increase
1970	1,265	—
1975	4,680	270%
1980	12,590	169%
1985	45,033	258%
1990	83,170	84%

Source: USDA, Aquaculture Situation and Outlook, various issues.

The early organized efforts to expand markets were made principally by producer organizations and publicly supported agencies. The Catfish Farmers of America (CFA) organization was formed in 1968, with one of its

main goals to promote and expand the sales of farm-raised catfish. Farmers supported CFA with annual dues based on acreage and with feed check-off funds collected by producer-owned feedmills in Mississippi. The CFA supported several activities to promote catfish, including fish fry's, cooking contests, meetings, research, and media events.

The Mississippi Department of Agriculture and Commerce provided critically needed support to the young catfish industry in Mississippi by: (1) providing office space and staff support to CFA; (2) lending staff support to promotional activities through the agencies' Marketing Division; and (3) cooperating with Mississippi Agricultural and Forestry Experiment Station (MAFES) to obtain a grant from the USDA's Agricultural Marketing Service to support the first marketing research for catfish. The Mississippi Farm Bureau also supported the young industry by organizing a Commodity Division for catfish. The Farm Bureau joined with CFA to sponsor a promotional booth at the American Farm bureau Federation's annual conventions for several years. Over a period of 5 years at major cities across the United States, samples of farm-raised catfish were served to an estimated 50,000 people representing all 50 states of the United States and many foreign countries. Surveys conducted during these conventions revealed most delegates were tasting catfish for the first time, and expressed extremely favorable reactions (Boleware and Dillard 1984).

The single most important market development effort was the formation in 1986 of The Catfish Institute (TCI) by two producer-owned feed mills. The purposes for TCI were to promote generically farm-raised catfish, and to help assure a quality product. TCI was originally formed as The American Catfish Institute, but was renamed TCI when producers in other states declined financial support. TCI is currently supported by a feed check-off collected by 3 catfish feed mills in Mississippi (shortly after TCI's formation, the third mill in Mississippi joined). In 1991, TCI budgeted $2.2 million for generic advertising, mostly advertisements in upscale, consumer oriented magazines. While these ads promote the attributes of farm-raised catfish in general, the ads are also designed to promote Mississippi farm-raised catfish. Shortly after its formation, TCI acquired the services of a reputable, nationally recognized ad firm to conduct market research, develop market strategies, and design and implement an effective ad program for Mississippi's farm-raised catfish. TCI also contracts with an equally reputable public relations firm to carry out a nation wide media program to enhance the image of farm-raised catfish and to increase public awareness. Based on its own market research and on one independent study (Kinnucan and Venkateswaran 1990), the TCI program has been very effective in expanding the market. TCI has been instrumental in opening new markets far from the traditional catfish consuming, deep south region.

In addition to the TCI's generic advertising program, brand advertising by individual processing and marketing companies has been significant. While the TCI program has targeted consumers, the processor's ads have targeted wholesale buyers at the food service and retail grocery level. High quality, full page brand advertisements are found regularly in trade magazines. Also, catfish processors frequently offer discounts to retail grocery stores and restaurants as an incentive for retailers to purchase ads in local newspapers. Although the level of expenditure by processors for advertising is not known, these efforts have, without question, contributed to market expansions.

The Mississippi Catfish Producers Marketing Association was formed in 1978 for the purpose of achieving what producer members believed to be more equitable prices. While the association had no power to set prices that were binding to processors, they did set what the association called official price and encouraged members not to sell below the set price. These actions undoubtedly had some impact (although never documented by research), especially during times when catfish were in short supply. This association became the Catfish Bargaining Association (CBA) in October 1989, with power to set minimum

farm prices. The first master agreement with processors went into effect the following month. While the CBA had initial success in stabilizing price at a level producers were generally pleased with, the association is having some internal problems at the present time. The severe over capacity in processing plants, with price cutting by non CBA members, is having an adverse effect on reaching a new agreement. In fact, plans for a new master agreement to take effect July 1, 1991, have been temporarily canceled.

Marketing research conducted by the Department of Agricultural Economics at Mississippi State University has contributed to market development. The first project, "Market Potential and Current Marketing Procedures and Practices of the Catfish for Food Industry," was initiated in 1979. This study included surveys of both producers and processors. Miller et al. (1981) described marketing practices of producers, and procurement and marketing practices of processors (MAFES Research Reports No. 129 and 130). Dixon et al. (1982) surveyed processors, supermarkets, catfish specialty restaurants and food brokers to gain information on market channels, market penetration and market potential (Dixon et al. 1982). The second major research project titled "Cost of Procuring, Processing and Distributing Farm-Raised Catfish" was initiated in 1983. Keenum and Dillard described harvesting and hauling practices of producers and processors, and estimated costs (Keenum and Dillard 1984). Another study concluded that processing costs decline substantially as size of processing plant increased (Fuller and Dillard 1984). The department conducted proprietary studies for TCI to determine shipments, by state, of Mississippi's processed catfish (confidential report to TCI). The Department was the lead institution for a regional marketing study titled "Analysis of Regional and National Markets for Agricultural Products Produced for Food in The Southern Region" initiated in 1988 by five cooperating southern states. National surveys of households, supermarkets, and restaurants provided a data base from which 8 research bulletins, 11 journal articles and 17 papers and other articles were prepared by the cooperating scientists. Four bulletins contain summaries of the survey results (Engle et al. 1990; Hatch et al. undated, McGee et al. 1989; Pomeroy et al. 1990).

The Mississippi Cooperative Extension Service (MCES) has actively supported the industry in Mississippi since 1968. The Food and Fiber Center (a special staff of industrial engineers, food technologists, and marketing economists within MCES) has assisted processors with developing new products, improving processing methods, quality control, and computer software. The Food and Fiber Center prepared feasibility studies for several producer-owned processing facilities. MCES has sponsored the Annual Catfish Processors Workshop for 18 years, where food scientists and technologists, engineers, quality control specialists and marketing experts from both industry and public agencies meet to solve problems and identify opportunities. A workshop proceedings has been published by MCES each year.

Product Development

Although little processing and marketing data are available for the first emerging years of the catfish industry, it is known from personal observations and conversations with producers and processors that most of the product in the early years was sold as whole-dressed fish, packed in ice. The first processing data collected and reported by the USDA were quantity delivered for processing, quantity sold fresh and frozen, and some price information. Not until 1986 were any data on product form included in the monthly report.

USDA initiated the "Aquaculture Situation and Outlook" in 1981. One year later this report was discontinued and not published again until 1988. These "Situation" and "Outlook" reports contain summaries of processing volumes, quantities of major product forms sold, prices paid to farmers by processors, wholesale prices received for major product forms, for the years in which data were collected. These are the only industry-wide processing and marketing statistics available.

During the past 15 years, there have been dramatic changes in the mix of product form. During the early years, most processed catfish were sold as fresh, whole-dressed. In 1975, approximately two-thirds of processed fish were sold fresh (ice-packed), with probably less than 20 percent sold as either filleted or steaked. There was very little further processing at that time. By 1980, further processed products of all kinds (including fillets) represented only 25 percent of all product sold.

Major changes occurred in the product mix during the last decade. By 1990, further processed (fillets and other) products represented more than two-thirds of all products sold, leaving less than one-third of the product as whole-dressed (Tables 2 and 3). Another important change has been the increase in sales of frozen product. In 1975, approximately one-third of all products were sold in frozen forms. The proportion of products sold in frozen form increased steadily, and by 1990 frozen products represented approximately 55 percent of all products sold (Table 4). Consumer acceptance of frozen products has been an important change for the industry. Even though fresh processed catfish has a shelf life of 12-14 days, the acceptance of the frozen product allows producers and processors to manage inventories more efficiently. Frozen products can be stored for up to 6 months with little deterioration in quality.

Other, and perhaps even more important, changes in product form have occurred during the past decade. Many new further-processed, value-added products have been developed and successfully introduced. The first value-added products consisted of pre-breaded, individually quick frozen (IQF) fillets, strips, and nuggets. These products found acceptance primarily in the restaurants, convenience stores, hot food counters, and the fast food sector. During the past 5 years, all the "Big Three" processors have introduced glazed, IQF portion controlled fillets, including such coatings as lemon-pepper, garlic butter, cajun and blackened. All these products are conventional and microwave oven-ready. These products initially were packed in the larger containers preferred by the food service sector. These and other value added, convenience products are gaining a share of seafood sales in grocery stores, packed in quantities preferred for home consumption. These new products are giving processors the opportunity for product differentiation and the potential for more brand loyalty among consumers. This of course enhances the pay-off brand advertising and should result in increased advertising

Table 2
Quantity of Major Product Forms of Processed Farm-Raised Catfish Sold by Commercial Processors, All Years Reported, United States

Year	Whole Dressed	Further Processed		
		Fillet	Other	Total
1986	24,032	19,084	8,601	51,717
1987	28,989	24,701	12,833	66,523
1988	25,191	29,156	13,572	67,919
1989	28,163	36,615	15,276	80,054
1990	26,818	39,492	16,860	83,170

Source: USDA, ERS. *Aquaculture Situation and Outlook*. Aqua-6. Mar. 1991.

Table 3
Percent Distribution of Major Product Forms of Processed Farm-Raised Catfish Sold by Commercial Processors, All Years Reported, United States

Year	Whole Dressed	Further Processed		
		Fillet	Other	Total
1986	46.5	36.9	16.6	100.0
1987	43.6	37.1	19.3	100.0
1988	37.1	42.9	20.0	100.0
1989	35.2	45.7	19.1	100.0
1990	32.2	47.5	20.3	100.0

Source: USDA, ERS. *Aquaculture Situation and Outlook*. Aqua-6. Mar. 1991.

Table 4
Percent of Processed Farm-Raised Catfish Sold Fresh and Frozen, Selected Years, United States

Year	Fresh	Frozen	Total
1976	65	35	100
1980	55	45	100
1984	52	48	100
1988	45	55	100

Source: USDA, ERS. *Aquaculture Situation and Outlook*. Various Issues

expenditure by processors to complement the generic advertising by TCI.

Summary and Conclusions

The growth of the farm-raised catfish industry from 1970 to 1990 is a story of developments in Mississippi. During this period, total quantity of farm-raised, commercially processed catfish in the United States increased from approximately 1.3 million kg to 83.1 million kg. The increase in value has been even more dramatic as product form changed from mostly whole-dressed fish to higher value, further processed forms. During this period, consumption has expanded from the traditional consuming, deep south region, to such distant states as California, Illinois, and New York, where large quantities are shipped weekly. Today, shipments to California are exceeded only by shipments to Texas.

This dramatic growth in the industry has not occurred by accident. Imaginative, hardworking, innovative producers and producer organizations have been largely responsible for this growth. Dedicated staff members in public agencies have also contributed greatly to the growth.

If United States per capita consumption of fish and seafood continues to increase as expected, aquaculture will, by necessity, produce much of the increase. No significant constraints have been identified that will prevent the farm-raised catfish industry from participating in this projected growth.

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The Development of the American Catfish Industry

by

James G. Dillard[1] and John E. Waldrop[1]

Introduction

The first known commercial production and sale of farm-raised catfish occurred in Arkansas in 1960. It was 14 years later before sufficient quantities of catfish were produced in all months of the year that producers began to claim industry status. Farm-raised catfish production and processing has developed into an important industry, especially in Mississippi, where production and processing is concentrated.

The U.S. catfish industry is comprised of 65,520 ha underwater producing catfish fingerlings and food-size catfish (Table 1). There are 1,818 operations reported in the United States, but are concentrated in the four southern states of Alabama, Arkansas, Louisiana, and Mississippi. Since 1980 water surface area developed for catfish production has almost tripled (Table 1). The U.S. industry includes at least 32 processing plants and at least 8 catfish feed mills.

Mississippi alone has over 300 production operations with more than 38,000 ha of water in production (Table 1). Mississippi has 12 processing plants, 5 feed mills producing scientifically formulated catfish feed, and numerous other businesses supporting the industry. One plant, a farmer owned cooperative, is the largest fish processing plant in North America. A 1990 survey (Department of Agricultural Economics 1990) revealed direct employment on catfish farms, in feed mills, and in processing plants in Mississippi totaled more than 7,000 persons with an annual payroll of more than $80 million.

Table 1
Number of Catfish Operations and Water Surface Area, Selected States and United States

	1980		1990	
	Number of Operations	Water, ha	Number of Operations	Water, ha
Alabama	260	3,136	350	7,527
Arkansas	139	3,124	206	8,296
Louisiana	31	304	200	4,654
Mississippi	204	13,201	308	38,041
Other States	327	2,283	754	7,002
United States	961	22,048	1,818	65,520

Source: USDA, ERS. *Aquaculture Situation and Outlook.* Aqua-6, Mar. 1991.

Development of the Industry

Even though catfish were successfully spawned and reared experimentally in Iowa as early as 1917 (Wellborn 1990), little else in the way of production, harvesting, and processing technology existed when producers in Arkansas first attempted commercial catfish production in about 1955. Even though production in Arkansas increased to more than 3,000 ha by 1966, production began to decline and all but vanished a few years later. The failure of the industry to develop in Arkansas was likely due to lack of production technology existed when producers in Arkansas first attempted commercial catfish production in about 1955. Even though production in Arkansas increased to more than 3,000 ha by 1966, production began to decline and all but vanished a few years later. The failure of

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the industry to develop in Arkansas was likely due to lack of production technology, including disease control, knowledge of nutritional requirements, and markets.

As interest in catfish production declined in Arkansas during the 1960's, interest increased in Mississippi. According to Wellborn:

> "There are many reasons that commercial catfish farming developed in Mississippi after 1965 rather than in Arkansas, Alabama, or in the other states where catfish were already being produced, not the least of which were hard-working farmers who weren't afraid to try something new and had the faith and determination to see a fledgling industry through difficult times. After about 1970, the story of commercial catfish farming is really the story of the Mississippi catfish industry. Although significant contributions were made by catfish farmers in other states and by researchers working at universities throughout the country, Mississippi catfish farmer and processors led the way in developing production, processing and marketing techniques that enabled the industry to grow without waiting for research to prove their value. Some factors that were of great importance in the development of the Mississippi catfish industry include: (1) the involvement of Mississippi State University and the Mississippi Department of Agriculture and Commerce; (2) formation of a cooperative catfish feed mill; (3) development of a production practice that allowed year-round production and harvest of food-size catfish; and, (4) formation of a farmer owned processing plant." [Wellborn 1990, p 10].

Stated another way, a "critical mass" of required factors came together at the right time and place to allow the catfish industry to flourish in Mississippi.

Contributions of Institutions

The importance of involvement by Mississippi State University (MSU) cannot be overemphasized. As production intensified in Mississippi (higher stocking densities and feeding rates) disease and water quality problems intensified. As a consequence, Dr. Wellborn began a fish disease diagnostic service at MSU in 1969. Later on, two Mississippi Cooperation Extension Services (MCES) diagnostic laboratories were established in the Delta where catfish production was concentrated. In 1971, Dr. Wellborn identified the presence of "broken back disease," indicating a possible Vitamin C deficiency. He then collaborated with Dr. Robert Wilson, biochemist at MSU, to verify the Vitamin C deficiency. Dr. Wilson's subsequent research on the Vitamin C requirement and minimum levels of essential amino acids along with their availability to catfish from various feed ingredients led to the production of a nutritionally complete catfish feed. In 1978, presence of "brown-blood" (nitrite toxicity) disease was discovered in farm-raised catfish. Again, Dr. Wellborn collaborated with other MSU scientists and found an effective and affordable treatment. These are some of the more important examples of problems alleviated by MSU scientists working with catfish producers.

As producers began to expand, intensify stocking rates, and apply higher feeding rates, critical problems were encountered in production management, harvesting, and marketing. In 1968, the Directors of both the MCES and the Mississippi Agricultural and Forestry Experiment Station (MAFES) committed funds for extension and research programs to assist the fledgling industry. The first fisheries specialist was hired by MCES in 1968. The Extension Wildlife and Fisheries Department was established in 1971, and Dr. Thomas E. Wellborn was hired as leader with a mandate to provide technical assistance to the catfish industry. The leadership of MAFES urged researchers to begin looking at problems of the emerging industry even before funds for this purpose were available. Dr. John Waldrop, Agricultural Economist, began researching

economics of catfish production as a resource development activity at least two years before funding was made available for catfish research. The early work by Dr. Waldrop and his graduate students, particularly on pond size, farm size, cost of production, and financial analysis put catfish farm planning on an economically sound footing. Economic analysis has been updated as prices and technology changed over the years, with the latest analysis published in 1988 (Foster and Waldrop, Burke and Waldrop, Waldrop and Smith, Keenum and Waldrop, Garrard et al.). Wellborn states:

> "Economic research was among the first conducted on catfish farming at Mississippi State University. This economic research initiated by Dr. John E. Waldrop and his students was of great significance to the new catfish farming industry. Initially, farmers tried all sizes of ponds, from 1 acre to 400 acres, with the average probably running from 40 to 80 acres. However, research showed, both in terms of economics and management, that a pond built on 20 acres was best. Because of their work the 20-acre pond became the standard size for production ponds throughout the major catfish producing areas" (Wellborn 1990, p 4.).

The early economic analysis suggested commercial production of catfish would be an economically viable enterprise, given the use of recommended production practices and expected prices. The commercial production in Mississippi has occurred and continues to occur because, on the average, returns exceed cost. This is a general statement and does not imply that all current production is profitable, or that a particular future producer's revenue will exceed his costs (Tucker 1985).

There is an abundance of cases in the United States where aquaculture enterprises, including catfish, have been started and eventually failed because insufficient revenue was generated to cover costs of all resources required to produce and market the products. These aquacultural entrepreneurs typically under-estimated resource requirement and costs, and/or over-estimated potential yields and demand for the product. This has not been the case with farm-raised catfish in Mississippi, where economic and financial feasibility have been carefully researched.

The Mississippi Department of Agriculture (a state agency) also provided critical support to the going catfish industry through promotion and marketing assistance. For several years, office space and staff support were provided to both the Catfish Farmers of America and Catfish Farmers of Mississippi. Other agencies and producer organizations contributing to the development of the industry are named in a companion paper titled "Product and Market Development in the American Catfish Industry" contained elsewhere (pages 53-59) in this Proceedings.

By discussing only developments in Mississippi, the authors are not suggesting that important developments haven't occurred in other states. There have been significant contributions by both researchers and extension specialists in a number of states in the United States. Researchers at Auburn University have conducted much research, particularly in the areas of reproduction, genetics, catfish nutrition, and water quality management, that has benefitted the U.S. catfish industry.

Growth Trends

The catfish industry continues to grow. Data in Table 2 show the actual and percentage increase in hectares in production and in quantity delivered to commercial processors. The exact production quantities are not known because all fish are not sold to processors and some "small" processors do not report their data. However, these unreported data represent a very small portion of the total and continue to decreases as a percent of total. Growth in output occurs from both increases in water area devoted to production and increases in productivity from existing water area.

Processing data are in terms of "roundweight" delivered to processors. As pointed out above, a portion of the total production goes to other markets and some very small processors may not report their data. Unfortunately, data are aggregated for the United States and are unavailable by state.

Table 2
Water Surface Hectares in Catfish Production and Kilograms Processed, Mississippi, 1991

Year	Hectares In Production In Mississippi	Percent Change	Kilograms Processed In United States	Percent Change
1980	11,056		21,075,932	
1981	16,337	47.76%	27,506,124	30.51%
1982	22,637	38.56%	45,089,812	63.93%
1983	25,208	11.36%	62,256,192	38.07%
1984	26,459	4.96%	69,969,609	12.39%
1985	26,233	-0.85%	86,916,447	24.22%
1986	29,777	13.51%	96,959,086	11.55%
1987	34,423	15.61%	127,232,151	31.22%
1988	36,373	5.66%	133,860,564	5.21%
1989	37,063	1.90%	155,084,823	15.86%
1990	38,041	2.64%	163,492,243	5.42%

Source: USDA, ERS. *Aquaculture Situation and Outlook.* Various issues.

Future of the Farm-Raised Catfish Industry

Growth over the past 10 years, measured by either data set, has been phenomenal. Obviously, the industry cannot continue to grow at the same percentage rates. However, there is no reason to assume that expansion will slow in absolute terms for the foreseeable future. There is no indication that the market is close to saturation. Current average per capita consumption in the United States is only 0.34 kilograms, annually. Based on current trends in food consumption and product availability, this figure will likely double or triple in the next 15 years.

This potential for continuing growth causes this industry to be an exciting area of research. Research problems range from gram water quality problems as production intensifies to capital supply for expansion, to increasing disease problems as more and more fish are crowded into the same water. Economics of production and marketing will continue to be challenging areas for economists.

From the viewpoint of the economists, the industry will become more competitive, but the future economically growth seems assured.

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Marketing and Financial Feasibility Analysis Considerations for Culturing Hybrid Striped Bass in a Dredged Material Containment Area

by
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Introduction

Aquaculture entrepreneurs, researcher biologists, and government agencies involved in promoting aquaculture for economic development have viewed hybrid striped bass a target species for commercial food fish cultivation. Hybrid striped bass generally refers to a cross between striped bass (*Morone saxatilis*) and white bass (*M. chrysops*). The original cross of this fish, called the palmetto bass, was first produced in South Carolina in the mid-1960's using eggs from striped bass and sperm from white bass. The reciprocal cross using white bass females and striped bass males is called the sunshine bass.

The hybrids of the striped bass, called hybrid bass in this report, have been considered a substitute for the declining striped bass supplies. While commercial striped bass landings fluctuated widely since the 1930's, landings generally increased through the 1970's. Since the mid-1970's, commercial landings declined from a record high of 14.7 million lb in 1973 to 2.4 million lb in 1982, and further declined to 0.3 million lb in 1989. However, a large part of the decline since 1982 resulted from restrictions on the commercial fishery, including moratoria in Maryland and Delaware and coastwide minimum-size limits.

Aquaculturists have found hybrid bass suited to culturing in earthen ponds, tanks, and raceway systems. Hybrid fry are usually raised in rearing ponds to 35-to 45-day-old fingerlings. Hybrid bass fingerlings can then be raised to various market sizes (>1 lb) in 15 to 24 months.

The purpose of this paper is to provide a U.S. situational analysis of food fish markets for hybrid bass through 1991 and a comparative financial analysis of dredged material containment area (DMCA) aquaculture of hybrid bass. This analysis should assist aquaculture technologists, investors and others in evaluating the potential of DMCA culture of hybrid bass.

Aquaculture Production

Regulatory constraints

The commercial culture of hybrid bass was slow to develop in the United States due to numerous state regulations governing the harvest and sale of striped bass and/or hybrid bass. Although these regulations were enacted to protect the wild striped bass stocks, in many states the regulations have limited the possession and/or sale of hybrid bass even if produced by aquaculture. These state-level rules and regulations were considered the largest single hindrance to striped bass and hybrid bass culture including activities ranging for broodstock collection to marketing. For example, in New York, only cultured hybrid bass or striped bass could be marketed. In comparison, since 1985, in Maryland, it was illegal to possess a striped bass or hybrid bass regardless of its origin. These conflicting regulations also created confusion on what was and was not legal regarding the possession and sale of striped and hybrid bass within states and when shipping fish to other states.

Since 1986 the recognition that culture of striped bass and its hybrids as food fish might

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be a feasible commercial enterprise has led to a change in the restrictions on possession and/or sale in several states. For example, in 1990, South Carolina modified its regulations to allow the cultivation and sale of the "reciprocal" cross hybrid striped bass (i.e., the sunshine bass). Maryland repealed its striped bass possession laws starting January 1, 1990.

Preliminary estimates of cultured production: 1990-92

There are no formal or consistent statistics kept on cultured striped bass and hybrid bass production in the United States. Total U.S. production of striped bass or its hybrids has apparently increased from less than 10,000 lb before 1985 to nearly 900,000 lb by 1989.

Preliminary estimates of aggregate production by regions were compiled by the Striped Bass Growers Association in 1991 (Rhodes and Sheehan 1991). These estimates are based upon questionnaires returned by producers. Most of the expected hybrid bass production in the South (Table 1) will be based upon earthen or cage culture systems with the important exception of SeaChick, Inc. in Mississippi using a tank system. In the Northeast, tank or raceway systems are expected to provide much of the production in 1991 and 1992. In the West, Aquatic Systems Incorporated (ASI) has been the major producer. ASI reported that its current (1990) production was greater than 0.6 million lb per year (Van Olst and Carlberg 1990).

Table 1
Estimated Regional Production of Food-size Hybrid Striped Bass, 1990-1992

Year	Region				
	West	Mid-west	South	North-east	All Regions
Low Estimates					
1990	700	10	280	160	1,150
1991	800	10	2,030	430	3,270
1992	1,600	40	3,970	1,300	6,910
High Estimates					
1990	700	10	690	160	1,560
1991	850	20	2,510	430	3,810
1992	2,100	50	4,940	1,300	8,390
Midpoint Estimates					
1990	700	10	490	160	1,360
1991	830	20	2,270	430	3,550
1992	1,850	50	4,460	1,300	7,660

Note: If there is only one estimate available for a region, all estimates for that region will be the same. U.S. Bureau of Census regions were used.
Source: Striped Bass Growers' Association. (Whole fish in thousands of pounds.)

U.S. Market Situational Analysis

Current Marketing Channels and Regions

Current market channels in the United States for hybrid bass appear to follow those described by Swartz (1984) except dockside buyers (primary wholesalers) serving as product assemblers of fish sold by producers are usually bypassed by aquaculturist. Currently, much of the hybrid bass cultured in the United States is either sold to secondary wholesalers or distributors (purveyors). A small amount is sold directly by producers to seafood retailers, supermarkets and/or restaurants. The Atlantic Coast states from North Carolina to New York, which has historically been the major region for commercially caught striped bass, is currently the dominate region for selling cultured hybrid bass. The buyers in the centralized market of New York City, the Fulton Fish Market, probably account for the largest percent purchased in the United States. Historically, the size of striped bass has influenced the geographic distribution of sales. For example, larger fish caught in Maryland were sent to New York while smaller fish were sold in Maryland (Swartz 1984).

Seasonal availability

In general, wholesalers prefer the option for purchasing hybrid bass year-round versus seasonally (Rhodes unpublished, and Wirth 1989). After year-round availability, I found that hybrid bass available in the first and fourth quarter of the year had the next highest buyer utility for Midwest wholesalers. The first quarter for mid-Atlantic wholesalers has apparently been a strong demand period for

hybrid bass. This buyer demand peak in the first quarter is probably due to increased consumer demand during Lent and weather limitations on United States and Canadian commercial fishing activities. It is often assumed that cultured seafood products should be able to receive a price premium for being able to provide a fresh product year-round. Except for tank or raceway systems using heated water, U.S. hybrid bass producers employing outdoor earthen ponds and cage systems are currently limited to seasonally harvesting a large percent of their market size fish. Factors requiring seasonal harvesting patterns of hybrid bass include cash flow needs, pond stocking logistics, and perhaps the risk of low temperature related winter kills.

Purchase price

Since buyers derive their preferences mainly on profit maximization, purchase price is a critical attribute in buyer preferences. Researchers logically assume that all buyers prefer the lowest possible price. Wirth (1939) and I both reported that price was the most important attribute in the preference rating when wholesalers were evaluating the purchase of hybrid bass. In contrast, restaurant buyers in the mid-Atlantic region gave product form, not purchase price, the highest preference rating (Wirth 1989).

Purchase price is affected by the other product attributes. The product form obviously influences the purchase price. Currently (1991) ex-pond purchase prices pay by U.S. freshfish wholesalers and distributors are in the following range: whole, from about \$2.00 to \$3.80 per lb; dressed (e.g., gutted only), about \$3.25 to \$4.75 per lb. In 1990, the secondary wholesale price of gutted, head-on hybrid bass to restaurants can range from \$4.25 to \$6.25 per lb. The size of whole fish also influences prices. In October 1990, SeaChick was pricing small (1.5 to 1.75 lb) fish \$0.30 lower than medium (1.75 to 2 lb) hybrid bass. Other producers have reported price differentials of \$0.40 to \$0.60 between small and large hybrid bass (>2 lb).

Substitutability

The development of commercial hybrid bass farming in the United States has been partially justified on the assumed market potential for cultured hybrid bass to serve as is a good substitute for small wild striped bass. Wirth (1989) reported that a majority of mid-Atlantic wholesalers felt that hybrid bass could substitute for wild striped bass in their markets. Wirth (1989) noted that seafood restaurants were not as certain of the substitutability. This was attributable to the restauranteurs' general lack of familiarity with hybrid bass. Some wholesalers and purveyors are still unfamiliar with the hybrid bass and consequently do not know about substitution of hybrids for other species. Moreover, hybrid bass' major market competitors apparently include the salmon and flounder at the restaurant level and wild striped bass, bluefish, and sea trout in the wholesale channel on the Atlantic Coast (Harvey et al. 1990).

Outlook: The U.S. Market and Production

In the United States, cultured striped bass and its hybrids do appear to have regional wholesale market niches on the Atlantic Coast. These niches have developed partly due to past marketing with wild striped bass by wholesalers and distributors. With the reopening of limited commercial fishing for wild striped bass on the Atlantic Coast and the expansion of cultured hybrid bass production, aggregate supplies of these fishes are expected to increase substantially in 1991 and 1992 even if growers have over-estimated their 1992 production. This situation raises the question of whether prices will fall substantially if producers are only able to target fresh fish market segments in the United States. Beyond 1992, expansion of aggregate aquaculture production of striped bass and its hybrids in the United States may be constrained by declining market prices. Some producers have tried to export whole, hybrid bass to Western Europe. The long-term viability of the European market is questionable given the

development of sea bass and sea bream cultivation in other countries. Perhaps experienced United States producers may have production cost advantages compared to European producers. This assumes among other factors that hybrid bass will be acceptable to European consumers.

Comparative Financial Analysis of DMCA Aquaculture

Assumptions and procedures

This financial analysis is based upon a synthesis of South Carolina's research (e.g., Smith 1988) at the Waddell Mariculture Center, Bluffton, South Carolina, and current commercial pilot scale production information. Cost estimates are a combination of actual reported costs by South Carolina aquaculturists and accepted engineering algorithms for estimating costs. No attempt has been made to compare and/or evaluate the financial desirability of hybrid bass farming in the United States. The desirability of investing time, money and other resources in any commercial enterprise can depend upon many factors (e.g., investment alternatives, life-style preferences, etc.).

The hypothetical non-dredged material containment area (DMCA) farm used in this preliminary analysis is based on a 60-acre hybrid bass farms using one main well comprised of fifteen 1-acre earthen ponds for fingerling stocking (Phase II) and eighteen 2.5-acre earthen ponds for yearling stocking (Phase III) with the total land being about 80 acres, 30 percent larger than total water-surface acreage of the farm. One of the 1-acre ponds would not be used for fingerling stocking; this reserve pond could be used for emergency situations and other contingencies.

The hypothetical hybrid bass farm design used in this analysis including the overall acreage and size of individual ponds may not constitute the optimal design. Individual ponds with more than 2.5 water acres are currently being used for commercial hybrid bass farming in the Carolinas.

The DMCA hybrid bass facility was assumed to have similar design and operating requirement. This assumption is not based upon any specific observations. It was assumed that the DMCA ponds would be much large (e.g., 5 acres or greater for the Phase III stocking) and consequently would require more equipment for spreading feed and harvesting fish. In addition, it was assumed that the remoteness of a DMCA site would require the use of generators to power electric paddlewheels (Table 2). This assumption was carried over to the projecting costs and returns where the DMCA facility fuel use was set at double the estimated energy use of the non-DMCA facility (Table 3). Given the preliminary nature of these data for a DMCA facility, no attempt was made to project future cash flows and associated capital budgeting variables (e.g., internal rate of return).

Start-up and operating cost comparison

Possible advantages and disadvantages of a DMCA site versus a typical earthen pond site have been summarized in Table 4. These suspected advantages and disadvantages are reflected in this preliminary analysis. Again, these estimates used for the DMCA facility are only the author's preliminary estimates. Based upon the above assumptions, the DMCA would capture significant construction cost savings but these savings would be decreased by higher equipment costs (Table 2). In addition, if a DMCA facility needs to suspend operations for a nine month or longer period while dredge material is being deposited at the site, this suspension could reduce the DMCA facility's profitability compared to a non-DMCA facility assuming no major operating savings were captured by the DMCA facility. These are only hypothetical comparisons of a DMCA and non-DMCA facility. These comparisons are intended only to identify some o the factors to consider when comp‿ing a DMCA versus a non-DMCA site. Obviously, research on the growth, survival, market quality and other factors related to hybrid bass culture at DMCA sites need to be conducted even before economic research is initiated.

Table 2
Hypothetical Initial Capital Costs for NonDMCA versus DMCA Aquaculture Facility for Culturing Hybrid Striped Bass

80 Acre Facility (60 Acres of Water)			
	Non-DMCA	DMCA	USACOE[1]
Preconstruciton costs	$ 20	$ 10	$ 15
Construction Costs:			
Earthmoving	144	72	100
Pumps & Water			
Control Structures	120	60	80
Access Roads	5	50	50
Site Improvements	50	30	0
Construction	25	25	40
Supervision			
Totals	$344	$237	$270
Ten Year – SL Depreciation[2]	$ 34.40	$ 23.70	N/A
Equipment Costs:			
Aerators	50	50	
Harvest Equipment	10	15	
Storage Sheds	10	10	
Vehicles	15	15	
Wiring for Aerator	48	48	
Generators	20	90	
Water Supply	60	20	
System	15	30	
Feeding Hardware	15	0	
Tractors &	0	20	
Accessories	20	40	
Work Boat			
Other Equipment			
Totals	$263	$388	
Five Year – SL Depreciation[3]	$52.60	$67.60	

[1] Possible U.S. Army Corps of Engineers' (USACOE) contributions to the site's preparation. Although these USACOE contributions could benefit the operation of the DMCA facility, they would *not* represent loan collateral or income value to the DMCA operator.
[2] The simple depreciation treatment used in this Table are for discussion purposes only and do *not* necessarily represent acceptable depreciation treatments for financial statements.
[3] The simple depreciation treatment used in this Table are for discussion purposes only and do *not* necessarily represent acceptable depreciation treatments for financial statements.

Table 3
Hypothetical Costs and Returns for Non-DMCA versus DMCA Hybrid Striped Bass Aquaculture Facility

Total water acreage of farm: 60	Non-DMCA	DMCA
Major assumptions:		
Yearling bass stocking, #/a	3,500	3,500
Grow-out survival rate (2nd year)	80.0%	80.0%
Harvest size, pounds[1]	1.8	1.8
Average market price, $/lb	$2.40	$2.40
Yield, lb/acre (whole) (in thousands)	5,040	5,040
Projected hybrid bass harvest, lb	302	302
Projected sales (in thousands)	725.80	725.8
Variable costs	**(In Thousands)**	
Fingerlings @ $ 0.25/ea lb[2]	$88.00	$88.00
Fish Feed @ $ 0.22/lb (FCR=2.5:1)	170.0	170.0
Electricity & fuel	12.0	24.0
Marketing & other costs	11.8	23.6
Total variable costs	$281.80	$305.60
Gross profits	$444.00	$420.20
Fixed costs	**(In Thousands)**	
Salaries & wages	$115.00	$125.00
Projected depreciation	87.0	91.3
Miscellaneous expenses[3]	30.0	40.0
Pond & other maintenance	15.0	10.0
Total fixed costs	$247.00	$266.30
Total costs	$528.80	$571.90
Projected net income before taxes	$197.00	$153.90

[1] Projected size after about 18-22 months of growth.
[2] These fingerlings would be harvested in the following year.
[3] Includes professional fees, insurance, rent, and vehicle expenses.

Table 4
Some of the Possible Relative Advantages and Disadvantages of a Dredged Material Containment Area Aquaculture Site versus a Typical Earthen Pond Culture Site

Possible Disadvantages of a DMCA Site

Less water quality control
Ex: Lower survival rates = Lower revenues[1]

Limited accessibility by land
Ex: Higher post harvesting costs

Fewer utility alternatives
Ex: Higher equipment and/or operating costs

Possible Advantages of a DMCA Site

Lower preconstruction costs
Ex: USACOE assistance in facility design and permitting

Lower construction costs
Ex: Reduced outside dike construction

Ample water supply
Ex: Owner pumping equipment costs

[1] This disadvantage was not used in the text's financial analysis.

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Farmers Home Administration United States Department of Agriculture Business and Industry Loans

by
Billy L. Curb[1]

Introduction

In recent years the support which agriculture gives to the economy of small towns has been eroding. At the same time, many farm families are no longer able to earn a living from farming and are seeking other sources of employment in these communities. The Farmers Home Administration (FmHA), as the lead federal agency in rural development programs, is involved in efforts to increase the non-agricultural jobs available in rural towns. Since 1975, the FmHA has provided loan guarantees to assist local lenders to provide the credit needed for expansion and preservation of jobs. The guarantees allow the lenders to make larger loans available, provide better rates and terms, and bring additional capital into the community through sale of the guaranteed portion of the loan.

Rural Area Defined

The larger rural communities often provide a source of jobs for smaller nearby towns so FmHA has expanded its traditional lending area to include cities of up to 50,000 population. Priority is still given to towns of less than 25,000 people. The suburbs and urbanizing areas that surround cities of over 50,000 people are ineligible areas.

Eligibility

Eligibility for a guarantee from FmHA begins with the determination of the impact on jobs. FmHA priorities are:

- Saving existing jobs.
- Expansion of existing businesses.
- New plant location or new business start-up.
- Business which will generate little or no permanent employment other than the entrepreneur.

Loan Size

There is no minimum loan size, and the maximum loan size that will be considered is $10 million. FmHA encourages applicants who may be eligible for assistance for the Small Business Administration (SBA) to see if such assistance is available from SBA.

Applicants

The applicant can be an individual, a partnership, corporation, cooperative trust or other legal entity, or an Indian Tribe. Individuals and a majority of the owners of other entities must be U.S. citizens or persons legally admitted for permanent residency in the United States.

Lenders

The lender must be a state or federally chartered bank, Savings and Loan Association, mortgage company that is part of a bank holding company, or insurance company regulated by the National Association of Insurance Commissioners. The Federal Land Banks, Production Credit Associations, and Bank for Cooperatives are also eligible to be lenders.

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[1] Farmers Home Administration, Temple, TX.

Quality Loans

The Business and Industry (B&I) program is unique in FmHA because there is not test for credit required. The applicant does not have to show that credit is not available elsewhere at reasonable rates and terms. FmHA is looking for quality loans that will support a stable employment source. Unprofitable, undercapitalized, and poorly managed businesses do not provide this stable employment source. The factors which FmHA looks for in determining loan quality include:

- **Equity**. A tangible balance sheet equity of 10 percent to 25 percent is required for new businesses or where higher risk factors are presented.
- **Profitability**. The strongest applications are those that can show at least three years of profitability and cash flow adequate to service the debt will need to service the debt and will need to demonstrate repayment ability based on realistic projections supported by detailed assumptions used in preparing the projections. FmHA may require feasibility studies done by recognized independent consultants to verify the projects.
- **Management**. Management must demonstrate experience in the industry and competence in production, marketing, finance, and personnel management.
- **Collateral**. All collateral must secure the entire loan with no separate collateral for the unguaranteed portion of the loan. Collateral should include hard-asset collateral such as land, buildings, machinery, and equipment, but can also include accounts receivable, inventory, and other items of value. The maximum loan to value ratio is 80 percent of market value of real estate, 60 percent of book value of good inventory and accounts receivable, and an amount to be determined by FmHA on equipment and other items.
- **Guarantees**. Personal guarantees are required from owners, major stockholders, or partners unless the stock is so widely held that no one individual can exercise control or the business is financially strong, has a good earnings history, and abundant collateral is available. Corporate guarantees are required of parent, subsidiary, or affiliated companies unless legally restricted or prohibited by existing contractual obligations.

Eligible Loan Purposes

There is no requirement that the business be related to agriculture. Many types of businesses including manufacturing, retail and wholesale trade, services an processing are eligible. FmHA does expect that the number of jobs supported will be in relationship to amount of the loan request.

Purposes for which the loans can be used include:

- Business and industrial acquisitions.
- Purchase of land, machinery, and equipment.
- Construction, enlargement, or modernization.
- Pollution control or abatement.
- Working capital.
- Refinancing when it is necessary to save jobs.
- Eligible fees and costs.

Ineligible Loan Purpose

There are also some uses for which B&I loans cannot be used.

The major restrictions are that funds cannot be used to:

- Relocate jobs or to expand a business where there is already an excess of supply of the goods or services.
- Pay any distribution to an owner or beneficiary who will continue in the business.
- Transfer the ownership of a business unless the transfer is necessary to keep the business from closing or will expand job opportunities.
- Finance hotels, motels, tourism, recreation, charitable, religious, or fraternal organizations.
- Finance agricultural production with the exception of specialized crops such as forestry, commercial nurseries, aquaculture, hydroponics, mushrooms, or commercial custom feed lots.

Interest Rates

The loan guarantee provides additional assurance of repayment to the lender, but the loan commitment is between the applicant and the lender. Interest rates will be negotiated between the applicant and lender and are not subsidized by FmHA. They may be either fixed or variable. In determining if the rates are reasonable, FmHA will take into consideration the rate at which guaranteed loans are being sold in the secondary market.

Repayment Terms

Repayment terms are also set by the lender within maximum terms allowed by FmHA.

The maximum terms are:

- 30 years for real estate.
- 15 years or usable life for equipment.
- 7 years for working capital.

All loans must have a fixed repayment schedule. Lines of credit and revolving loans are not eligible.

Preapplications

Allocations are filled with the lender who then forwards the application to FmHA requesting the guarantee. Application forms are available from FmHA.

Applicants or lenders may also file a preapplication requesting a determination of eligibility from FmHA. If it appears that the project is eligible and loan guarantee authority is available, then they will be encouraged to file a complete application.

FmHA Review

Once an application is filed with FmHA, the review in the FmHA State and National offices will take approximately 30 to 60 days. If the guarantee is approved, FmHA will issue a conditional commitment to the lender. Equipment acquisitions and construction must then be completed before the FmHA guarantee is used. A fee of 2 percent of the guaranteed portion of the loan is payable to FmHA when the guarantee is issued.

Other Requirements

Information will be required by FmHA to comply with various laws and requirements. Environmental reviews may be required, and the applicant will be required to supply FmHA with the information required to complete the review. Projects must be in compliance with flood plain restriction, Clean Air Act, Water Pollution Control Act, historical preservation, and equal opportunities requirements.

FmHA will also consider state development strategies as identified through the intergovernmental consultation process.

The summary of the B&I program provides general information and highlights about the program. It is not intended to include all requirements and regulation.

Opportunites for CAAP

by
T. Neil McLellan[1]

Introduction

The U.S. Army Corps of Engineers (USACE) dredges approximately 300 million cubic yards of sediment every year maintaining the 25,000 miles of navigable waterways in the United States. This material must be relocated by one method or another. Relocation areas include open water (ocean or river) and upland. More and more dredged material is being used beneficially. Uses include, but are not limited to, beach fill, wetland and habitat (bird, oyster, etc.) creation, and providing suitable construction material or sbustrate. The type of disposal/beneficial use which is incorporated into the dredging process is determined by several factors including: quantity and type of material; location of channel within bay/estuary/landlocked reach; economic impacts; and environmental concerns.

The Corps has used upland levee disposal for many years for the safe and economical placement of dredged material. In several locations these areas are becoming full or the dredging cycle does not allow for proper management of the area. To alleviate this problem, the Corps and its local sponsors are always looking for new upland disposal areas. Difficulty often arises because of the landowners perception of the upland areas lost property because it reduces his ability to produce a cash crop. By incorporating aquaculture during the non-dredging cycle, the landowner can create an income producing enterprise for his property.

The suitability of upland disposal site for aquaculture will depend on several conditions including location, size, configuration, type of material, and dredging cycle. The potential aquaculturist will need to specify these requirements for any site identified. Part of the selection process will be the coordination between all parties involved in dredging and aquaculture: local, state, and Federal regulatory agencies; the landowner; the local Corps District's Operations and Maintenance section; the local project sponsor; and the aquaculturist. One of the first steps will be to identify locations that will be suitable sites for the Corps. This paper will provide an overview of the Corps' needs in a joint disposal/aquaculture project.

Site Potential

To be successful, a Containment Area Aquaculture Program (CAAP) site must benefit both parties to the greatest extent possible. When pursuing a new site, the aquaculturist must be aware of the Corps' requirement to maintain the channel. Although most districts will coordinate scheduling for dredged material placement or a site, it is the primary purpose for the Corps to utilize the site when required. In many instances, the Corps can move dredging dates 3 to 6 months to accommodate the aquaculturist, but dredged material placement will remain the primary purpose of the site. Several other considerations must be included to make the venture successful, including: site size; configuration and location; type of material; frequency of dredging operation; growing season; levee configuration; drainage patterns; water control structures; site accessibility; and type of mariculture crop. This paper will evaluate dredge cycle time, types of material, site availability, and size and site accessibility on a regional bases.

Dredging cycle time is of primary importance to the aquaculturist. To maximize production, the maximum amount of time is

[1] U.S. Army Engineer District, Galveston; Galveston, TX.

needed to produce as many crops as possible between dredging jobs. Excluding emergencies, some sites may be used every 10 to 12 years, or as often as every 6 months. Ideally the aquaculturist would want to use the site where cycle time is a maximum number of years. However, the Corps and its sponsors' highest need is at the high frequency end. Perhaps the best location for a site would be where the cycle time is every 2 to 5 years. By providing additional storage capacity at a site where the cycle is in the 2 to 5 year range, the aquaculturist may be able to skip every other cycle. The aquaculturist site would be used every 4 to 10 years while the historical site would be used on a alternate bases. This not only allows the aquaculturist additional seasons in production, but it also provides the Corps additional storage capacity and more time to adequately manage other disposal sites.

The type and quantity of material dredged and the type of material at the potential site is also extremely important. Sandy or very silty material will not make high quality levees, which are required for long periods of water retention. For long retention, a high percentage of clay is required. If no fine-grained material is available, a layer of silt/clay mixture may be used over the site to improve water retention capabilities. In addition, the dredged material loading rate/location must be such to compliment the aquaculturist's project. Most of the loading problems can be overcome by pre-project planning and design to properly place the inflow and outflow locations to compliment one another. Otherwise drainage patterns and project depth could be changed that would require large amounts of earthwork to make the project site more efficient.

Site availability, size, and accessibility is best evaluated on a case by case basis. However, these parameters can be evaluated on a regional basis when discussed in general terms. Site availability is of concern when locations near the dredging operation are dominated by wetlands, water, industry, or critical habitat locations. A high percentage of the Intracoastal Waterway, both the Gulf and Atlantic, passes through vast wetland areas with several of the areas limited to access only by water. Access on the mainland side, in some cases, is also limited to water. This may conclude that the aquaculturist may wish to look towards more industrialized locations where accessibility is high; however, competition for the property may also be higher. Most districts like large disposal areas (>100 acres). Although some disposal areas are as small as a couple of acres, most are larger than 50 acres. The Corps has shown, with the Brownsville Aquaculture Experiment, that larger ponds can be successfully managed; however, the aquaculture industry has yet to embrace the large pond concept.

Opportunities in Coastal Districts

Opportunities for CAAP exist throughout all Corps districts which perform dredging and require upland sites. The Corps performs dredging in the Great Lakes, Gulf, Atlantic and Pacific Coasts, and along the inland navigable waterways, as well as some areas overseas. Over these districts, several different growing seasons, water and sediment quality, and dredging cycle exist. In addition, upland areas range from several acres to several thousand acres in size. To obtain a better understanding of CAAP projects within the Corps of Engineers, all the Corps' coastal districts were canvased for potential CAAP areas. This paper does not speculate on the potential for CAAP in inland waterways or areas outside the continental United States. Opportunities in these areas will be on a district by district basis and should reflect similar findings comprised in this study. Information on potential areas for CAAP is available from the district office directly.

A representative, involved in the dredging process, was contacted in each district and questioned on its potential for CAAP. All districts canvased were interested in the CAAP process and would entertain any suggestions involving new upland areas. However, some locations have limitations due to availability of new sites, type of disposal, or the dredging cycle and may not be conducive to aquaculture. The districts canvased were along the Atlantic Coast, Gulf Coast, and Pacific Coast.

Atlantic Coast

The Corps of Engineers maintains 8 districts and 1 working division along the Atlantic Coast. They include the New England Division Districts: New York; Philadelphia; Baltimore; Norfolk; Wilmington; Charleston; Savannah and Jacksonville. In general, the most diversity is occurring along the Atlantic Coast compared with the Gulf or Pacific Coasts. Several different types of projects exist in the different regions. The Atlantic Coast does have a large contingent of small boat harbors. These harbors may provide good potential for CAAP. The Corps may utilize the upland site for small boat harbors, on the order of every 10 years or so. However, small boat harbors usually have a higher percentage of private users than other types of placement areas who may place material more often than the Corps of Engineers.

New England Division

Located on the north Atlantic Coast, the New England Division has several project harbors that it must maintain. Most of the dredging projects are located along the coastline in salt or brackish water with a high percentage of the dredging conducted by clamshell dredges. The material is mostly fine-grained and is normally placed in offshore designated sites. Upland areas for dredged material are quite rare and most of their projects are on a relatively long dredging cycle (about 10 years). These projects tend to be on the smaller size (less than 200,000 cu yd) and currently do not require upland disposal. There are some small boat harbors that have upland locations, but they are limited. However, land acquisition costs are fairly high for any waterfront property in the coastal areas. This high initial capital cost could impair a CAAP project. Aquaculturists do grow salmon in net pins in deep water in locations along the coastline.

New York District

The New York District encompasses New York City and several surrounding areas including Long Island. Most of their dredging occurs in support of the Port of New York and inlet channels along Long Island. Most of this material is either relocated offshore or, if suitable, used to nourish beaches. In addition to these saltwater areas, some freshwater areas are located near Albany. The upland areas which are used in the Albany area are surrounded by wetlands. Obtaining new sites is difficult. The New York District is looking for new methods of relocating dredged material. Everything from creating offshore islands to filling existing submerged sand pits has been evaluated. Addition of any new upland sites would be a great asset to the district. As in New England, the cost of land is extremely high in New York and may be the limiting factor in acquiring an aquaculture site.

Philadelphia District

The Philadelphia District has a very active dredging program and is in dire need for additional upland areas. Almost all sites are from salt/brackish water and are used annually, in some cases more often. Philadelphia is also relatively unique in that the federal government owns most of the upland areas currently being used. The sites are in such short supply that continuing management is being done at each site to actively dry the material and provide additional space for more material. Sites that have been filled are being converted to wetlands through environmental initiative. Under these conditions it would be difficult for a CAAP project to have enough time to produce a crop between dredging cycles. As in all generalities, there are exceptions to the rule if someone wished to attempt a CAAP project in the Philadelphia District. The district is interested in obtaining access to new upland areas and would work with a CAAP project within the limits of each individual project.

Baltimore District

The Baltimore District is located on the upper portion of the Chesapeake Bay and is responsible for dredging several harbors and approach channels including several systems.

The district has requirements for upland areas in fresh, salt and brackish waters along the maintained waterways. The district has utilized dredged materials in the past for beneficial uses, including the creation of oyster reefs, and is extremely interested in the potential for a CAAP project within its jurisdiction. The district has even pursued a permit for growing hybrid stripped bass in an upland site, but the project was left wanting for a sponsor. With the district's diverse dredging schedule, identifying, coordinating and implementing a CAAP project that benefits all parties should not be a problem. With the district located on the Chesapeake Bay and the large demand for seafood in the immediate area, the success of a CAAP project should be high.

Norfolk District

Located on the lower portion of the Chesapeake Bay, the Norfolk District has been utilizing dredged material beneficially for many purposes, including creation of oyster beds, bird habitat, and beach nourishment. Several dredging methods are employed in dredging the fresh, salt and brackish waters in the area, and more upland areas are required to efficiently fulfill their dredging mission. Dredging cycles for the district range from 1 to 8 years with 6 to 8 years being most common. Norfolk would be interested in identifying new areas to utilize every other cycle so that both sites could be better managed. With the demand for seafood products in the area, Norfolk District would be a successful location for a CAAP project.

Wilmington District

Located in North Carolina, the Wilmington District performs dredging for several harbors and inlets. Much of this material is placed upland, in beach fill or offshore. Current upland areas range in size from 2 to 800 acres, with the average area being 5 to 10 acres. Much of the material dredged is silt; however, higher quality sands, are often sold by the local land owner for fill/construction material. In cooperation with the U.S. Fish and Wildlife Service, some of the upland sites are impounded to enhance them for duck habitat during the appropriate season. The district is in need of new upland sites and would cooperate on any CAAP project if it could be worked to mutual benefit. With the smaller size disposal areas currently utilized in the district and a favorable dredging cycle, a CAAP project may be identified which could add two or three ponds, thereby creating a situation where the aquaculturist would always be able to produce a crop.

Charleston District

The Charleston District currently maintains 70 diked upland areas. New areas are needed, but their location requirements would displace wetlands. Other potential areas have a higher best use, such as port development. The district would like to try a CAAP project, but limited space and availability for new sites make such a project difficult.

Savannah District

The Savannah District maintains several waters, including sections of the Intracoastal Waterway and Brunswick Harbor. Material in the channels constitutes mostly silts and sands. Upland disposal sites up to 700 acres in size are currently being used. The Savannah District is looking for new upland areas; however, the current upland sites in the Brunswick Harbor are used every 9 months to 1 year. The upland areas along the intracoastal waterway are not used as often, but accessibility of the areas is limited. With these restrictions, it would be difficult to create a CAAP site within the Savannah District.

Jacksonville District

The Jacksonville District maintains sections of both the Gulf and Atlantic Intracoastal Waterway and several large and small harbors up and down the Florida coast. Upland disposal areas range from 7 to 100 acres and are generally used every 3 to 5 years. Much of the material that is dredged from maintained inlets is beach quality sand and used for nourishment of adjacent beaches. Much of the material dredged and placed in an upland site has a

high sand content with some silt. The district is in need of disposal areas in the interior of the state and would be interested in any new areas being made available. The relatively warm climate, dredging cycle, and sediment type would be conducive to an aquaculture project. Land availability may be of some concern, but should not be as limiting as a location further north along the Atlantic Coast.

Gulf Coast

Four Corps Districts are located along the Gulf Coast of the United States. Since Jacksonville has already been mentioned, only Mobile, New Orleans, and Galveston will be mentioned here. In general, the Districts along the Gulf Coast account for most of the dredging conducted by the Corps of Engineers. Projects are divided into small draft harbors, normally associated with the Gulf Intracoastal Waterway, and deep draft harbors servicing the several large ports in the region. Because of this large amount of dredging, the upland requirements, and the long growing season, the Gulf Coast region has the most opportunity for a CAAP project.

Mobile District

The Mobile District maintains several deep draft channels, including the Mobile Ship Channel, and several shallow draft, including the Tennessee-Tombigbee Waterway and sections of the Gulf Intracoastal Waterway (GIWW). The district is looking for new upland areas in support of their dredging projects in both salt and fresh water. Closer to the coast, the greater the need for upland sites. The Mobile District has been extremely innovative with its dredged material in the creation of offshore berms, use of thin layer placement, marsh/wetland creation, beach nourishment, and habitat creation. In addition, management of some sites to provide duck habitat has been conducted. Dredging cycle in the district range from 1 to 8 years, with the average cycle being approximately 3 years. The district is extremely interested in obtaining new upland areas and would be willing to cooperate for the long term use of new placement areas.

New Orleans District

The New Orleans District maintains a large section of the Mississippi River and several other ports and harbors including reaches of the GIWW. Currently the districts uses a limited number of upland areas. With the erosional problems occurring all along the Louisiana coastline, the district has been utilizing dredged material for beneficial uses. A large portion of the dredged material is currently being used in the creation of wetlands along the Louisiana Gulf coast. The district also uses river placement, removing the requirement for upland sites. With the emphasis on land creation, there is a reduced demand for upland areas; therefore, the district is not actively looking for new disposal sites.

Galveston District

The Galveston District maintains approximately 1000 miles of channels, including shallow draft and deep draft channels. A significant percentage of the material dredged is placed in upland sites. The district is continually looking for more upland areas to place material from the channels. Galveston has conducted several beneficial uses of dredged material, including the creation of an underwater berm, wetlands, and the only CAAP project completed to date. The first CAAP project utilizing shrimp was conducted in Freeport in 1975, as well as the recently completed Brownsville CAAP project. The district would cooperate with any new site for placement of dredged material. Dredging cycles range from every year to every 10 years. Most of the materials dredged are silts and clays, with a smaller percentage being sand. Upland sites range from 20 acres to over 1,000 acres. Minimum size requirements can be negotiated, but the district prefers locations 100 acres and larger.

West Coast

The Corps of Engineers has four districts along the West Coast of the United States, Seattle, Portland, San Francisco, and Los Angeles. The West Coast is characterized by much

deeper natural ports than the Atlantic or Gulf Coasts. In general, much of the material dredged is sand and placed in open water. Requirements for upland sites are reduced. When they are required, material is often sold for construction materials. Although the opportunities do exist, a CAAP project along the West Coast may be more difficult to coordinate than along the other coastlines.

Seattle District

Very few upland areas are used in the Seattle District. The district is large dredging projects are in Grays Harbor and Puget Sound, where the material is placed almost exclusively in open water. Upland property in any of these areas is expensive and would be difficult to compete with other uses, residential development etc. The upland sites, that are currently used, are provided on a commercial basis. The material which is placed upland is subsequently sold for construction of various projects. The district has used material to create intertidal habitat, beach nourishment, and other beneficial uses, but may have a difficult time incorporating a CAAP project.

Portland District

Most dredging conducted by the Portland District is by hopper dredge, with placement in open water. A high percentage of its dredging needs is to remove sand and sandy shoals from the river and bay channels. The only location, where upland placement operations are used, is for some of the small boat harbors. Much of this work is done by private enterprise, and the upland sites, which are maintained, are very small, as small as 2 acres. Although aquaculture in this area includes salmon, crab and clams, it does not appear to be a conducive area for a CAAP project.

San Francisco District

In addition to San Francisco Bay, the district maintains many rivers and other coastal harbors along the California coast. Much of the sediment dredged from the bays and inlet channels is placed offshore or in the open water. However, several of the river locations utilize upland disposal, and more sites are needed to accommodate the projects in the area. Several small private boat harbors maintain upland dredged material sites also. The San Francisco District has used dredged material for several beneficial purposes, including habitat development and beach nourishment. Of all the districts located on the west coast, San Francisco has the highest potential for a CAAP project.

Los Angeles District

The dredging program in the Los Angeles District currently dredges mostly sands. This material is used for beach nourishment and land development, or is placed offshore. Much of the upland disposal currently being conducted is used for the expansion of the Los Angeles/Long Beach Harbor project to create new emergent lands for port development. All dredging projects involve salt water and have a dredge cycle of 1 to 3 years. Even though land is at a premium in and around southern California, the district would be interested in a CAAP project if an upland area would be made available. A CAAP project may be made difficult not only because of the land premium, but of the high percentage of sand dredged from the channels.

Conclusions and Recommendations

The Corps of Engineers conducts a vast dredging program, which requires large land areas for periodic placement of dredged sediments. Additional land is always required for dredged material placement, which provides an opportunity for the initiation of a CAAP project. The cost to the aquaculturist for developing can be reduced by taking advantage of the levees and water control structure which the Corps must build to maintain their upland sites. The requirements for the Corps to place dredged material in an upland site may be as long as every 6 to 10 years. This provides the aquaculturists several years of production between placement operations.

Aquaculture has proven compatible with upland dredged material placement sites. An investigation of the Corps' Coastal Districts provided some incite to the areas with highest potential for a CAAP project. The Gulf and Atlantic Coasts have the highest potential followed by the Pacific Coast. Although none of the districts canvased stated they were not interested in a CAAP project, some districts showed extreme interest and have even done some preliminary work on research and have provided access to potential aquaculturists.

Site Selection and Planning for Aquaculture in Dredged Material Containment Areas

by
Jurij Homziak[1]

Introduction

The U.S. Army Corps of Engineers (USACE) has the mission to maintain, improve and extend the navigable waterways of the United States. It has the regulatory responsibility for the dredging and disposal of over 450 million cu yd of sediment annually from over 400 ports and 25,000 miles of coastal and inland waterways (National Research Council 1985).

Since the enactment of laws designed to reduce th use of the ocean as a receiving area, disposal of much of this dredged material has shifted from open-water disposal to disposal into Dredged Material Containment Areas (DMCAs). These DMCAs receive approximately 40 percent of dredged material generated from coastal dredging activities. To avoid confusion, DMCA and confined, diked, or contained disposal sites or areas are synonymous.

Estimates suggest over 7,000 acres of new diked disposal areas are needed annually (Lunz and Konikoff 1987a, 1987b). Therefore, both the USACE and port/waterway management bodies have an ongoing interest in acquiring real estate for DMCA construction. However, suitable real estate is often difficult and expensive to acquire.

One proven way to overcome these difficulties is to develop attractive alternative uses of DMCAs that are compatible with disposal needs. Since DMCAs and aquaculture ponds share many characteristics, the use of diked disposal areas for aquaculture has been a major area of interest. This report is part of a series of extension documents and technical reports intended to make the technology developed under this research program available to the public.

As currently designed, most DMCAs are not generally suitable for aquaculture without substantial modification. The siting and design of successful dual use structures is complex, and a thorough understanding of the intricacies involved in site selection, planning, and design is essential for anyone seriously considering such an undertaking. This document provides a general overview of site selection needed to develop DMCA for dual use as disposal sites and aquaculture ponds.

Dredging, Disposal, and DMCAs

It is important to note that DMCA aquaculture will be confined to newly constructed facilities. The purpose of integrating aquaculture into disposal operations is to make new disposal acreage available for DMCA construction. Only a new site can provide this benefit to the USACE and the local dredging sponsor. Unless an idle disposal area is brought back into use, there will be no retrofitting of existing sites for aquaculture.

The primary purpose of a diked containment area is to receive and retain dredged material. Because the basic purpose of a DMCA aquaculture program is to promote the acquisition and retention of sites for the confined disposal of dredged material, aquaculture will remain the secondary or alternative use of any containment site. Site designs and operational requirements for aquaculture in DMCAs must allow the site to function in its primary role without impediment.

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[1] Mississippi State University, Biloxi, MS.

For both material disposal and aquaculture to be successful, the containment area site must be selected and designed with both primary and alternative use needs in mind. Those planning such multiple use DMCAs must be familiar with current containment area siting, design, and construction requirements in order to incorporate compatible modifications for aquaculture.

Dredging and disposal operations under the authority of the USACE are conducted according to specific guidelines. Where disposal into a diked containment area is the selected disposal option, criteria and procedures for the siting, design, construction, and operation of such facilities have been established (Palermo et al. 1978). It is essential that these guidelines be consulted before considering aquaculture as an alternative use.

Confined disposal areas receive hydraulic dredge effluent, the combined mixture of dredged material solids and overlying water from the dredging site, retaining the solids while allowing the clarified water to be released. Containment areas are designed and operated to meet two objectives: (a) to provide adequate material storage capacity for the dredging requirements of the project and (b) to effectively retain solids in order to meet established effluent suspended sediment guidelines (Palermo et al. 1978, Palermo 1988). These objectives are interrelated and dictate the design, operation, and management of the containment area from the CE viewpoint.

Selection Process

Selection and evaluation of an area for dual use (material disposal and aquaculture) is a four-tiered process. Concept feasibility must first be determined. The development of DMCAs for material disposal and aquaculture can only occur in USACE districts where DMCAs are planned, where additional DMCA acreage is required, and where district interest in the concept is present. Once feasibility has been established, compatibility of the proposed aquaculture operations with disposal requirements must be established. Aquaculture operations must not interfere substantially with the use of the site for dredged material disposal.

Once compatibility has been established, the selection and evaluation of candidate sites can proceed. First, areas potentially useful for confined disposal sites within the dredging project area are identified and their suitability for DMCA construction is determined. Aquaculture suitability is determined only for those sites suitable for DMCA construction. Coordination with the USACE district and the project sponsor is essential in the site selection, evaluation and project planning processes.

Concept feasibility

Establishing contact and coordinating the evaluation of aquaculture project feasibility with the responsible USACE district is the necessary first step in the area selection and suitability assessment process. Feasibility of a disposal - aquaculture dual use DMCA can be determined from information available held by the USACE district or contained in Port Management Plans.

Four factors will determine initial feasibility:

- There are active dredging projects which use DMCAs for disposal.
- Additional diked disposal acreage is needed.
- Interest in developing a dual use DMCA exists at the district.
- There is interest by the landowner; aquaculture will allow consideration of sites otherwise unavailable.

Once a feasibility has been established, contact should be made with the local dredging project sponsors to determine compatibility with dredging operations and to identify candidate sites for dual use DMCAs. For non-Federal projects, local authorities have the responsibility of locating and transferring disposal easements for DMCAs to the USACE. The USACE is the sponsor for Federal projects.

Support from both the USACE and the local dredging sponsor is essential for the successful development of dual use DMCAs.

Compatibility of operations

Detailed information about the dredging project for which confined disposal areas would be built must be assembled from the responsible USACE district and port or waterway management agency. This information will serve to both identify potential sites for DMCA and establish the compatibility of planned aquaculture activities with project disposal requirements. At least the following project information will be needed:

- Project locations which would require additional confined disposal areas, along with potential sites for such areas.
- Project schedules, particularly frequency and duration of dredging cycles.
- Restrictions, if any, on dredging to specific times of the year.
- Volume of material to be removed per dredging cycle and capacity/projected life of a given diked disposal area.
- Physicochemical characteristics of the material to be dredged. This includes the presence (and amounts) of any contaminants of potential concern or a reason to believe that contaminants may be present (Tatem 1990).
- DMCA design specifications, including location of dredge discharge point, spur dikes, etc.
- DMCA management strategies for increasing site capacity (dewatering, raising levees).

Site suitability for DMCA and aquaculture

Criteria and procedures for the siting, design, construction, and operation of diked disposal areas have been established (Palermo et al. 1978). Table 1 summarizes the main points to consider in evaluating a site for material disposal.

Table 1
Summary of Dredged Material Containment Area Site Selection Factors

Factors	Criteria
Land use	Material disposal should be compatible with adjacent land use.
Water Quality/hydrology	No long term effects on water quality.
Soil characteristics/ geological conditions	No leachate migration to groundwater; good foundation soils.
Meteorological conditions	Sites not subject to flooding, runoff, extreme winds.
Access	Construction of access routes possible.
Environmental concerns	Environmental and historical features of the area must be protected.
Social factors	Public input required for sites near populated areas.
Institutional factors	Regulations on material disposal and land use must be identified.
Economic factors	Cost of building and operating site, environmental protection, pumping/transportation acceptable.

Source: Soil Conservation Service (1977).

Ideally, the evaluation of the site for aquaculture should be a part of the DMCA site selection process. This re-emphasizes the need to coordinate the planning effort with the USACE district responsible for evaluating potential sites. The Soil Conservation Service (SCS) can frequently provide information on the suitability of a site for pond construction. Existing soils and topographic information on file at the SCS, and on-site surveys and the professional opinion of the SCS representative are valuable services that should be used.

Site selection for aquaculture involves the assessment of numerous physical variables. In most cases, budget constraints preclude all but the most essential soil tests and engineering analyses. In DMCA aquaculture, however, data will have been generated by the USACE in

evaluating the site for construction of a confined disposal area. Coordination with the USACE will improve the quality of site engineering while significantly reducing time, effort, and cost to the aquaculturist.

Aquaculture evaluation checklist

The following checklist is provided by Wilson, Homziak, and Coleman (in press) to assist with the aquaculture site selection

Aquaculture Evaluation Checklist

I. Background work.

- A. Determine feasibility and compatibility of dual use DMCAs. Contact the CE and solicit their cooperation. Contact project sponsor to establish support.
- B. Determine project locations that require additional DMCAs.
- C. Identify and secure all relevant documents and maps, and identify information resources:
  1. Large scale base maps.
  2. Topographic maps.
  3. Aerial photographs.
  4. CE documents.
  5. Port management plans.
     - a. Post disposal evaluation report.
     - b. Environmental reports and assessments.
     - c. Project documents, including previous projects in area.
     - d. Construction and project specifications and invitations for bids.
  6. Contacts and information sources
     - a. Permit and review agencies.
     - b. Site owners and landowners along access routes.
     - c. Dredging contractors.
     - d. Local economic development assistance groups.
     - e. Other aquaculture operations in local area.
- D. Review culture techniques and biology of the target species.
- E. Develop preliminary production and business plans.

II. Preliminary survey.

- A. Locate all candidate sites in area.
- B. Determine dredging schedule, season, lengths of time site will be used for disposal.
- C. Determine access, power supply lines, other basic services to site.
- D. Determine characteristics and volume of material to be deposited at site.
  1. Estimates of in situ sediment volume.
  2. In situ sediment concentration, void ratio or water content.
  3. Specific gravity of material.
  4. Degree of saturation.
  5. Coarse grained fraction (No. 200 sieve).
  6. Settling behavior of the material.
  7. Contaminant status (present, reason to believe, absent).
- E. Evaluate current soil characteristics at site.
  1. Soil classification (Soil Conservation Service).
  2. Soil particle size and shape.
  3. Permeability/porosity of soil.
  4. Percent clay content.
  5. History of contamination (agricultural, industrial).
- F. Evaluate hydrological properties of source water (monthly means, ranges, monthly and annual minima and maxima).
  1. Temperature.
  2. Salinity.
  3. Tidal range (avg. and maximum).
  4. Solutes.
  5. Nutrients.
  6. Dissolved gases.
  7. Contaminants, agricultural runoff, sewage, wastewater.
  8. National Shellfish Sanitation Program (NSSP) classification (surface marine water sources).

III. Evaluate disposal operations data.

- A. Frequency of disposal operations.
- B. Duration of site closure.
- C. Season(s) or months of year dredging scheduled (include regulated restrictions).
- D. Discharge rate, net volume retained.
- E. Length of time site will be used.
- F. New work/maintenance work (If new work, repeat evaluation of dredged materials and site design for maintenance work conditions.)
- G. Compatibility of site for disposal of dredged material and aquaculture based on dredging operations schedule.

(Continued)

Aquaculture Evaluation Checklist (Concluded)

IV. Evaluate disposal site data.

A. Foundation conditions of base strata.

1. Depth.
2. Thickness.
3. Extent.
4. Composition.

B. Ground-water conditions.

1. Depth.
2. Hydraulic gradients.
3. Down gradient use.

C. Site location and topography.

D. Proposed disposal area design.

1. Dike dimensions.
2. Weirs (number and placement).
3. Spur dikes.
4. Intended ponding depth.
5. Height per lift of material.
6. Intended storage capacity of site.
7. Other features.

E. Soil properties (for new disposal site; repeat for material after disposal).

1. Soil type.
2. pH.
3. Eh.
4. Organic carbon.
5. Cation exchange capacity.
6. Engineering data.

F. Site-specific meteorology and climate.

1. Water budget (rainfall, evapotranspiration).
2. Wind data (direction, average speed, maxima).
3 Tidal data (cycle, maximum and minimum heights).

G. Site specific management plans.

1. Proposed future site refurbishing plans.
2. Dewatering.
3. Future dike elevation methods.
4. Borrow area placement.
5. Other management requirements.

process. These are minimum suggested requirements to be investigated. Additional items particularly those of a site-specific or project-specific nature may frequently be required.

Project Planning

Design considerations

It is not uncommon in aquaculture projects for major design decisions to have been made and fixed prior to seeking engineering assistance. This can be a serious problem that may threaten project viability or add considerable cost to the operation. Consultation with professionals in the site selection design and construction phases of the planned operation is strongly advised. Coordinated decision-making is even more important in containment area aquaculture where site selection, design, and construction inputs from the local USACE district are essential to project success. The following description of the planning process is adapted from Kövari (1984) and Huguenin and Colt (1989).

Project objectives

Project planning is usually considered to include all of the activities short of the decision to implement the project. A critical first design step is the definition of project objectives. Because all current and future project needs must be considered, all explicit and implied assumptions included in the project objectives must be clearly identified.

Multiple use of DMCA requires multiple goals. It is important to order priorities and resolve conflicts in order to arrive at design decisions. Since disposal of dredged sediments remains the primary focus of DMCA use, the aquaculturist must fit and adapt the aquaculture pond design and management process into this procedure in order for dual use to be possible. Other factors, such as successive disposal events, will alter the DMCA site in ways that will affect long-term dual use. These modifications must be estimated and planned around.

Project objectives and physical data for the selected site are related in designing the

aquaculture facility. Design is a complex and iterative process. Decisions (including future plans) regarding species to be cultured, site characteristics, farm size, water sources and anticipated demands, stocking densities, production cycles, management options, access and utilities provisions, equipment and supply needs and maintenance, reliability and replacement schedules, and others must be made early and in detail. As these project decisions are combined with information developed during the planning process, broad objectives will be refined into increasingly detailed statements that are successively incorporated into the plan. The apparent redundancy in the planning process outlined below simply reflects the iterative and progressively complex nature of the decision making process.

Planning outline

Project preparation and planning should include the following steps:

- Identification of the project; an outline defining species cultured, culture system, and production target.
- Feasibility plan.
- Detailed production plan.
- Preparation of cost estimates.
- Preparation of contractual documents.

Identification of the project

The first steps in project planning are the definition of the project, identification of project objectives, and a broad concept of the design of the production facilities. This is an integral part of the site selection and evaluation process for any project.

Decisions regarding project objectives are incorporated first into the feasibility plan and finalized in the production plan. While the subjective nature of these plans should be recognized, they are needed to progressively guide facility design. Both feasibility and production plans are based on the number of steps in the production cycle, the amount of time required, and survival in each step. This information is used to calculate values for all of the major variables (e.g. water volumes, inflow and out flow, feed and other inputs, production level and timing, labor, etc.) employed in the planned production process. Other factors, including environmental conditions, technical variables and skills of personnel and others will affect these estimates. Because all of these variables are interdependent, tradeoffs will be necessary between production goals and water quality, stocking densities, operational procedures, feed requirements, equipment needs, economics, and levels of acceptable risk.

Feasibility or outline plan

The purpose of the feasibility plan is twofold. The first function is to confirm that the project can be developed at the selected site. The second is to collect and provide all data, calculations and plans needed for project approval and detailed planning.

The following data and maps should be available for the selected site:

- Maps
  - Contour maps (1:25,000 to 1:50,000).
  - Map showing legal ownership.
  - Soil or geological map.
  - Water resources map, including surface water sources, dry water courses, wells, water tables and characteristics and yield estimates.
  - Climatological map showing nearest meteorological stations and mean monthly values of temperature and rainfall.
- Meteorological data, mean monthly rainfall, evaporation humidity, wind speed and direction, and sunlight (solar radiant flux).

- Hydrological data.
  * Discharge, yield flood and water elevations for existing water sources, including any data on restrictions or competing uses.
  * Tidal data for marine/brackish water sites.

The feasibility or outline plan is usually the basis for permit applications and for securing external financing for the project. The plan should illustrate the technical feasibility of the project. Production calculations and design should be presented in sufficient detail to allow for reliable cost estimates to be made.

The main parts of the feasibility plan are as follows:

- **Report**. This should contain the most important information on the project, including a site description, soil characteristics (determined during the survey and assessment phase), water sources, and results of water analysis, pond discharge estimates, and meteorological data used in planning. The report should provide the proposed operations plan with production calculations, planning considerations, site layout (with roads, buildings and other facilities), arrangements of the water supply, and drainage. An abstract of capital, operational and production costs, analysis of benefits, and the proposed construction program should be included. A list of legal documents acquired or applied for to allow the project to proceed should be appended as well.
- **Maps and plans.**
  * General location map (unscaled).
  * Site map (scale 1:2000 to 1:5000, depending on project size), showing boundary lines, project site, existing features, contour lines, water source and drainage locations, and the locations of soil test pits.
  * Layout map (scale 1:1000 to 1:5000), showing arrangement of ponds, water supply and drainage systems, locations buildings and other works, proposed approach roads, and utility lines.
- **Structures**. A list of all proposed buildings and their plinth areas, and a list of equipment needed for the project.
- **Soil and water tests**. Soil and water test results for engineering and production calculations, in tabular form.
- **Cross sections**. Typical outline cross-sections of dikes and channels, showing slopes and dimensions.
- **Cost estimates**. Cost estimates for civil works, showing major quantities and unit rates for each item (buildings, structures, earth work, utility supply, engineering, equipment, and physical contingencies. Estimates of operational costs and production costs should also be provided.
- **Schedules**. A project schedule, based on project characteristics and quantity calculations, should show the time required for the activities required to complete the detailed plans.

Production calculations

Project designs depend on the type of farm under development and the scale. Production calculations based on the production plan are the core of the planning process. These calculations usually contain the information presented below, prepared for a planned fish farm.

Production Calculations

I. Production facility data.
   A. Production target.
   B. Culture method.
   C. Species cultured.
      1. Stocking rate.
      2. Initial weight.
      3. Harvest weight.
      4. Survival rate.

(Continued)

Production Calculations (Concluded)

- D. Requirements for broodstock, fry, fingerlings.
- E. Seed stock sources.
  1. Reliability.
  2. Quantity.
  3. Quality.
- F. Feed requirements.
  1. Types.
  2. Storage and delivery.
  3. Feed conversion.
- G. Fertilizer.
- H. Pond management.
  1. Water quality standards.
  2. Pre-treatment needs.
  3. Aeration.
  4. Treatment of effluent.
- I. Pond specifications.
  1. Types of ponds.
  2. Size and number of ponds.
  3. Water depths.
- J. Harvesting specifications.
  1. Methods.
  2. Schedule.
  3. Facilities.
- K. Operations plan.
- L. Marketing plan.

II. Hatchery.
- A. Production goals.
- B. Proposed technology.
- C. Operations plan.
- D. Facility specifications.
- E. Management requirements.

Detailed plan

Once the feasibility plan has been completed and approved, the data should be reviewed, and any deficiencies should be corrected. Any modifications to the proposed operating schedule, water management needs, and water calculations should be completed before detailed planning starts.

Information Resources

Where aquaculture is well established, such as in the deep south catfish belt or the Louisiana crawfish region, both public (Cooperative Extension Service, Soil Conservation Service, University) and private sector expertise in site selection and planning is available. Where aquaculture is a novel industry, however, it is up to the individual to seek out expert assistance and to become familiar with the basic principles of site selection, pond design and construction.

While this report provides an adequate overview of site selection, additional information is worthwhile searching out. The USACE Technical Reports on containment area aquaculture are valuable resources. Reviews in FAO/UNDP (1984), Huguenin and Colt (1989), Mayo (1988), Murray et al. (1986) and Wheaton (1977), are excellent sources of aquaculture project design and engineering information. Species culture guides, published by the Cooperative Extension Service, USDA Regional Aquaculture Centers and Sea Grant programs, often discuss site selection, commercial design, and construction procedures (e.g., Giudice et al. 1981, Ulmer 1990, Wellborn 1988). Finally, the SCS provides information on site evaluation, pond design, and construction.

Acknowledgements

This work was sponsored in part by the NOAA/National Sea Grant College Program, U.S. Department of Commerce, under Grant Number NA90AA-D-SG802, through the Mississippi-Alabama Sea Grant Consortium. Supporting funds for this grant were provided by the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. The U.S. Government, Mississippi State University, and the Mississippi-Alabama Sea Grant Consortium are authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear within.

This is Mississippi-Alabama Sea Grant Program Publication No. MASGP-90.

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Chemical Considerations of Aquaculture in Dredged Material Containment Areas

by
Henry E. Tatem[1]

Introduction

The effect of sediment contaminants on aquaculture has received little attention because aquaculture operations are not generally located at or near contaminated or industrial sites. Aquaculture operators have always been interested in water quality (Dupree and Huner 1984, Stickney 1979, Griffin and Mitchell 1988) but less concerned with sediment quality. Past emphasis on water quality over sediment quality is most likely related to the fact that contaminants in water tend to affect aquatic organisms quickly, causing either depth or abnormal behavior within a matter of hours or days. Contaminants in sediments, however, are generally less bioavailable and therefore are often ignored.

Tatem (1983) concluded that some sediment contaminants were potentially available to some aquatic organisms. This was not seen as an insurmountable problem, primarily because many dredged material containment areas (DMCAs) contain sediments that are not contaminated. Laboratory tests (both chemical and biological) are available to identify dredged material that would be suitable for an aquaculture operation. The Corps currently tests most dredged material for potential environmental effects prior to disposal. These tests establish the acceptability of the material for open-water disposal. Similar tests can be used to demonstrate the acceptability of a DMCA for aquaculture.

Numerous studies indicate that most dredged material is primarily sandy and does not contain elevated levels of contaminants or cause adverse biological effects (Saucier et al. 1978; Gambrell, Khalid, and Patrick 1978). Many DMCAs are relatively uncontaminated (Landin 1988) and are suitable for aquaculture (Lunz et al. 1984, Lunz 1985, Lunz and Konikoff 1987).

One way to provide an aquaculture operator with data on what contaminants may be found in sediments and to illustrate high concentrations is by specific examples. Sediment chemical analyses were performed during bioassay/bioaccumulation studies conducted at the USAE Waterways Experiment Station (WES) since 1978. Tables 1 and 2 present general examples of chemical analyses of either reference (uncontaminated) or contaminated sediments. Table 1 contains data from reference sediments, including one (BV1) from the Containment Area Aquaculture Program (CAAP) demonstration site at Brownsville, TX. Table 2 contains data on contaminated sediments. Most of the contaminated sediments could be characterized as heavily contaminated and were being studied to determine whether they were acutely toxic or caused significant bioaccumulation in exposed animals. Previous efforts to relate sediment chemical concentrations to biological effects have been only partially successful (Giesy 1988) because sediment contaminants are not generally bioavailable in the same sense that contaminants in water are. Sediment chemical data are used to indicate the presence/concentration of specific contaminants and whether bioassays or additional analyses are necessary (Engler 1988). Tables 1 and 2 can be used as general guidance in determining whether a DMCA sediment more closely resembles a typical reference sediment or has characteristics similar to a typical contaminated sediment. A key sediment parameter to consider is percent

[1] U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table 1
Chemical Analysis of Typical Reference Sediments[1]

Parameter	BV1	PENS	WEEK	PERD	PKAD	MSRI	BC-1	NYRE	$(X)^2$
Miscellaneous									
Sand,%	33.00	—	—	—	—	55.00	—	99.00	(62)
Silt,%	29.00	—	—	—	—	15.0	—	0.10	(15)
Clay,%	38.00	—	—	—	—	30.0	—	0.90	(23)
TOC,%	0.28	0.08	0.08	0.12	1.00	1.1	—	0.10	(0.4)
TVS,%	—	0.32	0.50	0.40	3.70	2.4	—	1.20	(1.4)
Fe,%	2.30	0.30	0.18	—	3.10	1.6	—	0.90	(1.4)
COD, ppm	5,490.00	3,860.00	8,420.00	1,260.00	9,025.00	27,000.0	—	1,245.00	(8043)
TKN	321.00	103.00	189.00	51.00	365.00	1,870.0	—	56.00	(422)
NH3N	5.90	—	—	4.00	—	210.0	—	6.00	(57)
TP	496.00	35.00	46.00	21.00	498.00	867.0	—	99.00	(295)
O and G	—	1,260.00	5,040.00	—	5,290.00	230.0	—	12.00	(2366)
Metals, ppm									
As	4.90	0.90	1.00	0.10	17.50	2.3	8.2	4.10	(4.9)
Cd	0.40	0.04	0.10	<0.05	0.23	4.5	0.8	0.04	(0.8)
Cr	20.00	1.30	31.70	0.30	69.90	54.7	123.0	20.00	(40.1)
Cu	18.90	2.60	4.00	.00	27.90	25.3	82.7	5.30	(21.0)
Pb	6.4000	1.300	3.2000	1.30	9.3000	104.000	118.00	13.00	(32.1)
Mn	452.0000	4.300	19.8000	8.40	384.000	652.000	—	110.00	(233)
Ni	17.9000	3.000	2.8000	0.20	32.6000	24.000	52.70	4.30	(17.2)
Zn	64.7000	11.000	10.7000	2.00	97.8000	93.400	248.00	19.00	(68.3)
Hg	<0.1000	0.070	0.3000	<0.01	0.2100	0.120	1.60	0.03	(0.3)
Ag	3.3000	—	—	<0.01	—	—	0.90	0.03	(1.1)
Be	1.1000	—	—	—	—	—	0.80	0.70	(0.9)
Se	—	—	—	—	—	—	0.80	1.00	(0.9)

(Sheet 1 of 3)

NOTE: BV1 = Brownsville, TX; PENS = Pensacola, FL; WEEK = Weeks Bay, AL; PERD = Perdido Bay, FL; PKAD = Delta, LA; MSRI = Mississippi River at St. Paul, MN; BC-1 = Hackensack, NJ; NYRE = NY Reference, New York, NY.

[1] All data is mg/kg or ppm dry weight unless otherwise noted. The values presented are only examples of reference sediments used in evaluations of dredged material disposal. They are not all-inclusive and so not represent sediment quality criteria.

[2] Mean levels for each parameter.

Table 1 (Continued)

Parameter	BV1	PENS	WEEK	PERD	PKAD	MSRI	BC-1	NYRE	(X)
PCBs, ppm									
Ar 1242	<0.0002	0.020	0.0200	<0.01	0.5100	0.020	<0.01	<0.43	
Ar 1248	<0.0002	—	—	—	—	—	0.14	<0.43	
Ar 1254	0.0270	0.020	0.0300	<0.01	0.7800	0.070	0.16	<0.43	
Ar 126	<0.0002	0.002	0.003	—	0.0800	—	0.10	<0.43	
T-QUAN (4)[3]	0.0276	0.042	0.053	<0.01	1.3700	0.090	0.41	<0.43	(0.0)
PAHs, ppm									
Naphthalene	<0.2000	<0.002	0.0002	<0.01	0.0001	<0.015	<0.84		(0.15)
Methylnaphthalene	—	<0.002	0.0004	<0.01	<0.0001	<0.010	—	<0.14	
Acenaphthylene	<0.2	—	—	—	—	—	<0.8	<0.07	
Acenaphthene	<0.2	—	—	—	—	—	<0.84	<0.01	
Fluorene	<0.2	—	—	<0.01	—	—	<0.84	<0.05	
Phenanthrene	<0.2	<0.002	<0.0001	<0.02	<0.0001	—	<0.84	<0.05	
Anthracene	<0.2	—	—	<0.01	—	—	<0.84	<0.07	
Fluoranthene	<0.2	—	—	0.10	—	—	<0.84	<0.04	
Pyrene	<0.2	—	—	0.10	—	—	<0.84	<0.15	
Benzo (a)								<0.14	
anthracene	<0.2	—	—	—	—	—	—		
Chrysene	<0.2	—	—	0.10	—	—	<0.84	<0.11	
Benzo (b)								<0.03	
fluoranthene	<0.2	—	—	—	—	—	<0.84		
Benzo (k)								<0.04	
fluoranthene	<0.2	—	—	—	—	—	<0.84		
Benzo (a) pyrene	<0.2	—	—	0.10	—	—	<0.84	<0.18	
Indeno (123cd)								<0.02	
pyrene	<0.2	—	—	—	—	—	<0.84		
Dibenzo (ah)								<0.07	
anthracene	<0.2	—	—	—	—	—	—		
Benzo (ghi) perylene	<0.2	—	—	—	—	—	<0.84	<0.09	
								<0.08	
T-QUAN (17)[3]	<0.2	<0.002	<0.001	0.42	<0.001	<0.015	<0.84	0.18	(0.2)

(Sheet 2 of 3)

[3] Total quantified.

Table 1 (Concluded)

Parameter	BV1	PENS	WEEK	PERD	PKAD	MSRI	BC-1	NYRE	(X)
Pesticides, ppm									
Gamma-BHC	<0.002	—	—	—	—	<0.001	<0.001	<0.010	
Heptachlor	<0.002	—	—	—	—	<0.001	<0.001	<0.010	
Aldrin	<0.002	—	—	—	—	<0.001	<0.001	<0.010	
Endosulfan 1	<0.002	—	—	—	—	—	<0.001	<0.010	
Dieldrin	<0.002	—	<0.001	—	<0.001	<0.001	<0.001	<0.020	
DDE	<0.002	0.850	0.014	<0.01	0.010	—	<0.001	<0.020	(0.1)
Endrin	<0.002	—	—	—	—	<0.001	<0.001	<0.020	(0.01)
DDD	<0.002	0.013	<0.001	<0.01	<0.001	—	<0.001	<0.020	(0.01)
DDT	<0.002	0.030	<0.001	<0.01	<0.001	<0.004	<0.001	<0.020	
Chlordane	<0.002	—	—	<0.01	—	—	<0.010	<0.040	
Toxaphene	<0.002								
T-QUAN (11)[3]	<0.002	0.890	0.014	<0.01	0.011	<0.004	<0.010	<2.000	(0.4)
Phenols and Phthalates, ppm									
Pentachlorophenol	<0.020	—	—	—	—	—	—	<0.053	
Di-n-octylphthalate	<0.020	—	—	—	—	—	—	<0.135	
Bis(2-ethylhexyl) phthalate	1.200	—	—	—	3,300	—	—	<0.165	

(Sheet 3 of 3)

[3] Total quantified.

Table 2
Chemical Analysis of Typical Contaminated Sediments[1]

Parameter	PA	LIS	BRH	BC-2	BC-3[2]	GB	AK	(X)
Miscellaneous, % and ppm								
Sand,%	—	—	—	—	—	27.00	55.00	(41)
Silt,%	—	—	—	—	—	32.00	22.00	(27)
22 Clay,%	—	—	—	—	—	41.00	23.00	(32)
TOC,%	2.24	2.05	4.32	—	—	4.10	3.90	(3.3)
TVS,%	4.81	4.29	12.60	—	—	10.70	7.40	(8.0)
Fe,%	4.12	2.80	1.75	—	—	4.50	3.70	(3.4)
COD, ppm	119,300.00	74,670.00	213,000.00	—	—	68,267.00	59,057.00	(106,859)
TKN	2,930.00	1,430.00	4,250.00	—	—	1,133.00	817.00	(2,112)
NH3N	—	—	576.00	—	—	78.70	25.30	(227)
TP	2,070.00	1,050.00	1,720.00	—	—	538.00	1,096.00	(1,295)
O and G	6,801.00	4,680.00	19,900.00	—	—	1,880.00	1,790.00	(7,010)
Metals, ppm								
As	24.80	33.20	10.10	10.3	22.2	14.4	35.30	(22)
Cd	1.60	1.30	18.50	15.8	33.1	13.2	8.50	(13)
Cr	196.00	139.00	1,290.00	414.0	917.0	296.0	196.00	(493)
Cu	304.0	143.0	2,115.0	268.0	571.0	367.0	436.00	(601)
Pb	88.3	57.3	278.0	297.0	392.0	382.0	387.00	(269)
Mn	393.0	286.0	193.0	—	—	473.0	339.00	(337)
Ni	85.0	52.5	162.0	72.0	74.8	75.5	56.40	(83)
Zn	422.0	256.0	1,170.0	774.0	3,960.0	708.0	568.00	(1,123)
Hg	2.8	2.6	0.7	29.2	301.0	3.1	7.10	(50)
Ag	—	—	1.7	8.4	12.7	3.9	4.90	(6.3)
Be	—	—	—	0.8	1.0	2.7	2.20	(1.7)
Se	—	—	—	0.7	0.8	<1.4	6.20	(2.3)

(Sheet 1 of 3)

NOTE: PA = Perth Amboy, NJ; LIS = Long Island Sound, NY; BRH = Black Rock Harbor near Bridgeport, CN; BC-2 and BC- 3= Hackensack, NJ; GB and AK = New York Harbor, NY.

[1] The values presented are examples of contaminated sediments used in evaluations of dredged material disposal. They are not all-inclusive and do not represent sediment quality criteria.

[2] This sediment contained very high levels of Hg (>300ppm); some of the other metals were also present at high concentrations.

Table 2 (Continued)

Parameter	PA	LIS	BRH	BC-2	BC-3	GB	AK	(X)
PCBs, ppm								
Ar 1242	3.7	0.50	1.9	<0.10	<0.1	0.8	0.60	
Ar 1248	—	—	—	1.70	6.5	1.6	<0.90	
Ar 1254	1.5	0.80	8.2	1.40	2.9	1.8	1.10	
Ar 1260	0.2	0.08	—	0.05	0.9	1.5	1.05	
T-QUAN (4)[3]	5.4	1.40	10.1	3.70	10.4	5.7	3.70	(5.8)
PAHs, ppm								
Naphthalene	—	—	2.4	<1.20	1.5	0.4	0.30	(1.2)
Methylnaphthalenes (2MN, 1MN, 26DMN)	—	—	11.1	—	—	<0.3	0.20	
Acenaphthylene	—	—	0.8	<1.2	<0.9	0.3	0.3	(0.7)
Acenaphthene	—	—	0.3	<1.2	<0.9	0.3	0.2	
Fluorene	—	—	1.4	<1.2	<0.9	0.3	0.2	(0.8)
Phenanthrene	—	—	10.5	<1.2	1.4	0.8	0.3	(2.8)
Anthracene	—	—	4.1	<1.2	<0.9	0.6	0.3	(1.4)
Fluoranthene	—	—	10.4	<1.2	2.3	3.2	2.3	(3.9)
Pyrene	—	—	16.9		1.8	3.8	2.8	(5.3)
Benzo (a) anthracene	—	—	4.6	—	—	2.4	1.3	(2.8)
Chrysene	—	—	6.5	<1.2	<0.9	2.3	1.3	(2.4)
Benzo (b) fluoranthene	—	—	—	<1.2	1.5	1.5	1.0	(1.3)
Benzo (k) fluoranthene	—	—	1.8	<1.2	1.5	1.2	0.9	(1.3)
Benzo (a) pyrene	—	—	7.0	<1.2	<0.9	1.8	0.9	(2.4)
Indeno (123cd) pyrene	—	—	0.4	<1.2	<0.9	0.5	0.6	(0.7)
Dibenzo (ah) anthracene	—	—	—	—	—	0.3	0.4	
Benzo (ghi) perylene	—	—	0.4	<1.2	<0.9	0.5	0.6	(0.7)
T-QUAN (17)[3]	—	—	78.6	<1.2	16.3	20.5	11.9	(25.7)

(Sheet 2 of 3)

[3] Total quantified.

Table 2 (Concluded)

Parameter	PA	LIS	BRH	BC-2	BC-3	GB	AK	(X)
Pesticides, ppm								
Delta-BHC	—	—	<0.1	<0.01	<0.01	<0.04	<0.03	
Gamma-BHC	—	—	<0.1	<0.01	<0.01	<0.04	<0.03	
Heptachlor	—	—	<0.1	<0.01	<0.01	<0.04	<0.03	
Aldrin	—	—	<0.1	<0.01	<0.01	<0.04	<0.03	
Endosulfan 1	—	—	<0.1	<0.01	<0.05	<0.04	<0.03	
Dieldrin	0.002	0.001	<0.1	0.03	0.12	<0.08	<0.05	(0.05)
DDE	0.110	0.020	0.7	<0.01	<0.00	<0.08	0.22	(0.16)
Endrin	—	—	<0.1	0.08	0.20	<0.08	<0.05	
DDD	0.170	<0.010	0.5	<0.01	<0.01	<0.08	0.47	(0.18)
DDT	0.080	<0.010	<0.1	<0.01	<0.05	<0.08	0.77	(0.16)
Chlordane	—	—	<1.0	<0.05	<0.10	<0.16	<0.10	
Toxaphene	—	—	<2.0	<0.05	<0.10	<0.00	<0.00	
T-QUAN (11)[3]	0.360	0.030	1.4	0.11	0.34	<0.08	1.46	(0.54)
Phenols and Phthalates, ppm								
Pentachlorophenol	—	—	<0.1	—	—	0.20	0.11	
Di-n-octylphthalate	—	—	<0.1	—	—	0.48	0.41	
Bis(2-ethylhexyl) phthalate	—	—	13.4	4.70	7.3	31.7	27.70	(17.0)

(Sheet 3 of 3)

[3] Total quantified.

sand. More sand usually means lower total organic carbon (TOC) and total volatile solids (TVS) values and lower values for other contaminants like metals, PCBs, and polycyclic aromatic hydrocarbons (PAHs). Data for pesticides indicate that most sediments, even those containing substantial concentrations of metals, PCBs, and PAHs, contain less than 1.5-ppm total pesticides. Sediments found to be toxic to laboratory test animals should not be recommended for aquaculture operations where a crop is being produced for human consumption.

Dredged Material Pollution Potential

Methods for determining dredged material pollution potential were evaluated during the Dredged Material Research Program (DMRP). Sediment chemical analyses can be used to indicate the presence or absence of specific chemical contaminants, but the presence or absence of a specific contaminant may not directly relate to the environmental impact. Other tests were found to be more appropriate for predicting potential environmental impacts, such as the elutriate test and bioassay/bioaccumulation tests (Brannon 1978). The elutriate test measures the concentrations of contaminants released from dredged material into the water column under environmental conditions simulating open-water dredged material disposal; bioassay and bioaccumulation tests show whether sediment contaminants are available to aquatic organisms. All sediments, whether contaminated or not, contain metals and nutrients from natural sources (Brannon 1978). Other contaminants, such as PCBs, most petroleum hydrocarbons, and pesticides are not natural constituents of sediments. Thus, the presence of these kinds of contaminants usually indicates contamination due to human activities. From the results of the DMRP studies on the subject, Brannon (1978) concluded that, in most cases, contaminants associated with sediments containing silt, clay and organic carbon are generally not readily available to aquatic organisms. Elutriate tests conducted with contaminated sediments revealed that the only constituents released in significant quantities were manganese and ammonia nitrogen. Most naturally occurring metals in sediments are tightly bound to sediment particles and are relatively immobile and unavailable (Brannon 1978).

The potential environmental impact of sediments containing metals and organic contaminants such as PCBs and pesticides should be evaluated through bioassay testing or by comparison of sediments at a DMCA with nearby reference sediments. Reference sediments can be defined as sediments known to be uncontaminated or shown not to cause toxicity or bioaccumulation in laboratory bioassays. Low concentrations of organic contaminants (PCBs, pesticides, and petroleum hydrocarbons) near detection limits or in the low parts per billion (ppb) range should not be of concern if the sediments contain organic carbon. Organic contaminants in sediments containing substantial amounts of organic carbon, as well as silt and clay, are likely to be less available to aquatic organisms than organic contaminants in sediments low in such constituents.

The situation for PAH contaminants differs from that of PCBs, pesticides, and metals. The PAHs are not as persistent as the other contaminants in animal tissues and may be found, at low concentrations, in otherwise uncontaminated sediments due to either natural deposits of petroleum, normal oil drilling operations, or atmospheric deposition from fires and fossil fuel combustion. As many as 40 or more separate PAHs may be found in sediments, each with a different solubility and potential for toxicity and bioaccumulation (Neff 1979, Neff and Anderson 1981).

Contaminant Mobility

The mobility of sediment contaminants is heavily influenced by the physicochemical conditions that prevail in the sediment. Sediment contaminants considered by Gambrell, Khalid, and Patrick (1978) include mercury (Hg), Cd, lead (Pb), zinc (Zn), copper (Cu), nickel (Ni), chromium (Cr), arsenic (As), chlorinated and petroleum hydrocarbons (CH and PH), Fe, Mn, nitrogen (N), phosphorus

(P), and sulfur (S). Typical dredged sediments are anoxic (reduced) and near neutral in pH. Depending on the disposal methods and properties of the dredged sediments, changes in the physicochemical conditions at the disposal site may result in substantial mobilization of certain potentially toxic contaminants (Gambrell, Khalid, and Patrick 1978).

Disposal of dredged material into a DMCA can result in changes in the physicochemical properties of the sediment such as pH and oxidation-reduction potential, which in turn can affect contaminant association with sediment, amounts of reactive Fe and Mn, and contaminant mobility. For example, if dredged material placed at a confined disposal site is allowed to dewater and oxidize, the pH of the dredged material may decrease, resulting in increased mobilization of metals (Gambrell, Khalid, and Patrick 1978). However, if the site is reflooded, residual oxygen demand should be sufficient to cause the sediment to return to anaerobic conditions. Anaerobic processes can reverse the changes in the sediment caused by aerobic conditions, resulting in a neutral pH, the reformation of sulfides, and precipitation of mobilized heavy metals by the sulfides. If the DMCA is not subject to dewatering and oxidation, the physicochemical conditions in the dredged material should remain similar to those at the dredging site following a period in which settling of solids and sediment reequilibration occurs. Since DMCAs will not be drained and allowed to oxidize while a crop is being grown, the physicochemical conditions at the site should be similar to an open-water site. Heavily contaminated sediments should not be used for habitat development (such as aquaculture) because of possible contaminant introduction into food chains but that, in some cases, slightly and even moderately contaminated materials could be used for many purposes at upland disposal sites. Gambrell, Khalid, and Patrick (1978) divided potential sediment contaminants into three groups:

- High risk (Hg, Cd, and chlorinated hydrocarbons).
- Low risk (N, P, and Fe).
- Low to high risk, depending on environmental conditions and other factors (Pb, Cu, Zn, Ni, Cr, As, Mn, and petroleum hydrocarbons).

Aquaculture and Contaminants

Landau and Pierce (1986) reported that the shrimp *Penaeus vannamei* reared in a pond receiving wastewater that also contained sediments heavily contaminated with Hg (1 to 100 ppm) did not bioaccumulate Hg to levels any greater than those normally found in marine shrimp. The Hg found in shrimp tissues was associated with nonedible tissues rather than edible tissues. These results indicate that aquaculture in ponds containing contaminated sediments is feasible although additional research was recommended. Contaminants associated with sediment are not as available to aquatic animals as those contaminants present in water. When animals do bioaccumulate contaminants from sediments, the tissue concentrations are, in many cases, not substantially greater than the sediment concentrations, i.e., contaminants are not normally concentrated from sediments in the same manner that they are concentrated from water (Neff 1984). Animals containing low levels of most contaminants can be depurated (contaminants removed) by holding the animals in clean, flowing water. In addition, it appears that bioaccumulated contaminants are not generally associated with edible tissues.

The literature has shown that most dredged material is relatively uncontaminated and that many contaminants adsorbed to sediment particles, especially the metals, are generally unavailable to aquatic organisms. If there is any reason to believe (after review of existing data) that there will be a contaminant-related problem for an aquaculture operation, then toxicity/bioaccumulation tests should be conducted prior to initiation of the operation, or the site should be rejected. Animals cultured at a DMCA known to contain low concentrations of some contaminants should be monitored during

the grow-out period to ensure an acceptable product at harvest. Uncontaminated sediments may contain ppm levels of certain metals and still be appropriate for aquaculture operations, but should not contain similar levels of specific organic contaminants such as pesticides, PCBs, and specific petroleum hydrocarbons.

Bioassays of CAAP Soil Samples

Most dredged material, whether scheduled for open-water or upland disposal, is either known to be uncontaminated or is tested for environmental effects by some combination of particle size/chemical analyses and/or biological testing. The length of sediment toxicity tests is usually 4 to 6 days while sediment bioaccumulation tests are usually run for either 10 or 20 days. Methods for testing dredged material were published in 1977 and updated January 1990 and are available from Corps Districts. Each District has the authority, in conjunction with other agencies and the states, to determine what tests will be conducted for a given dredging project. Large or controversial projects, especially those near significant sources of contaminants, will be subjected to more testing compared with other projects. A DMCA containing material from an environmentally controversial project is not likely to be used for aquaculture.

It is possible that a DMCA would be proposed for aquaculture where the dredged material in the facility had received only minimal environmental testing. Material that will be placed at a DMCA may not be tested for open-water effects since it is not scheduled for open-water disposal. In this case the potential aquaculture operator should be prepared to work with the District and assume the responsibility for evaluation of the DMCA and the DMCA sediment for acceptability for aquaculture. The District should provide the aquaculturist with the information it has on the proposed site as well as any relevant Corps publications on DMCAs and aquaculture. There are many obvious questions to ask. What is known about the material placed at the site? What kind of material has been placed there in the past? Where did it come from and what analyses or tests have been conducted on this material or on other material taken from the same area? Were there animals in the sediment as it was placed at the DMCA? Are there any animals living at the DMCA? What is their condition? Have any chemical analyses been performed on these animals? Were the sediments screened for all possible contaminants, or were they analyzed for a few specific parameters such as Cd, Hg, and PCBs? Were any acute toxicity tests performed with organisms similar to those to be used in the aquaculture operation?

While some bioassays and chemical analyses can be expensive, there are sediment analyses that are relatively inexpensive. These include particle size data and the miscellaneous sediment parameters such as TOC, TVS, COD, and oil (O) and grease (G). Analyses for metals are not as expensive as those for organic contaminants like PCBs, pesticides, and PAHs. If the DMCA contains natural populations of animals like fish, clams, or shrimp, these should be examined and possibly analyzed as one way to avoid the cost of conducting the bioaccumulation tests. Of course, if the initial sediment analyses do not indicate any substantial concentrations of contaminants, there would be no need for tissue analyses of test animals or those found at the DMCA site.

Surface soil samples, consisting of dry, aged dredged material, were obtained from five sites within the CAAP demonstration site and from the adjacent ship channel (Figure 1). Samples were taken with a shovel from five spots in Area A and one spot along the edge of the Brownsville Ship Channel (BSC). Approximately 10 liters of soil were taken from each location to a depth of 48 cm. Soil from Area A was dry while material from the BSC was wet. These samples were transported to WES and tested in the laboratory using mysid shrimp, *Mysidopsis bahia*, and penaeid shrimp, *P. vannamei*, the potential aquaculture animal. Separate bioassays were performed for each of the two species. The dry soil samples were stored in soil bags at 4 °C prior to being tested.

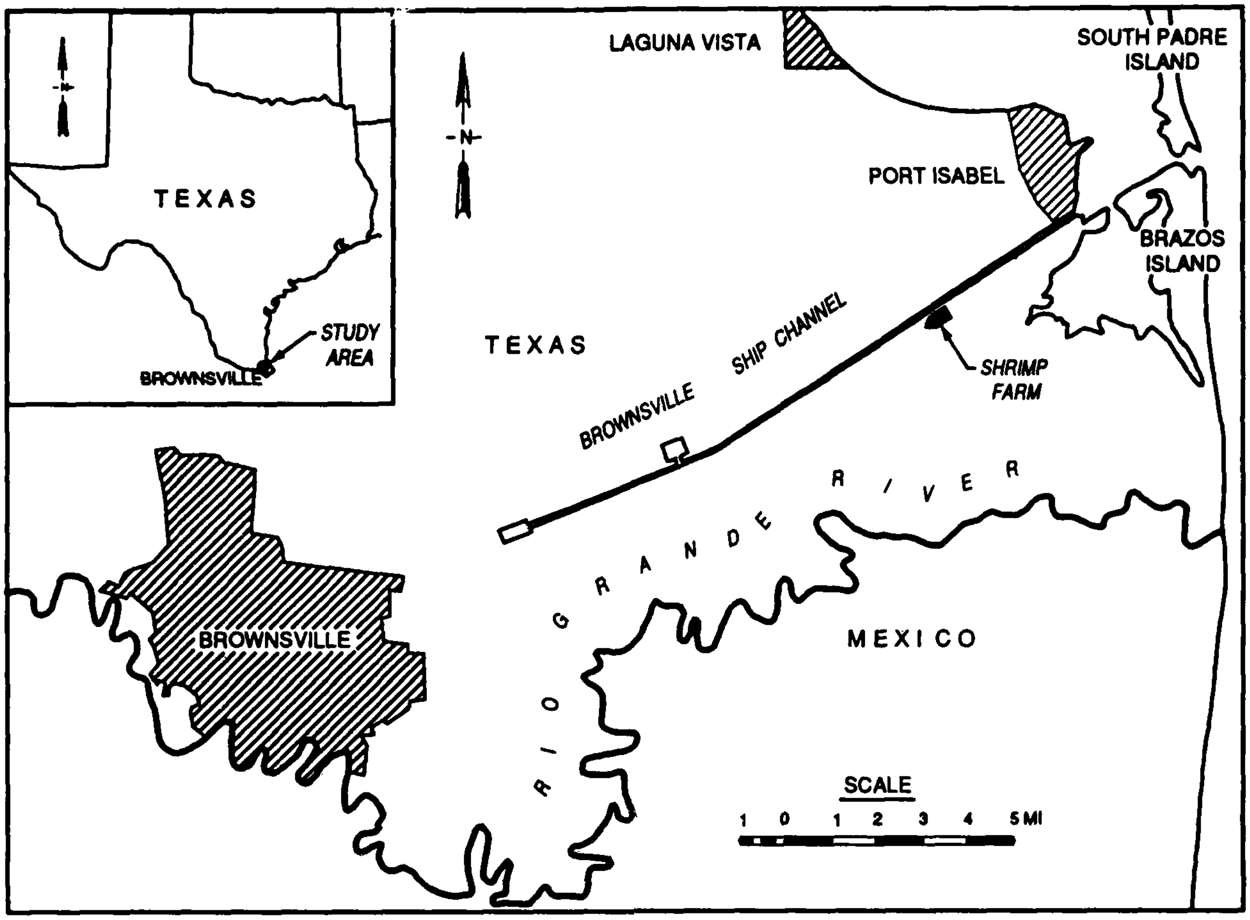

Figure 1. Sketch map of CAAP demonstration site (Area A) on the Brownsville Ship Channel N, Brownsville, TX, showing sediment sampling locations

Soil and 14-ppt seawater were placed in glass jars at a ratio of 1:4, sediment to water. Soil and seawater were stirred by hand, then placed on a shaker platform, and shaken for 40 min at 120 rpm. Afterwards, the mixtures were allowed to settle overnight (16 to 20 hr). Dissolved oxygen (DO) in the water over the soil (the supernatant) was determined the next morning. The DO concentration was 7.5 ppm, a level near 95-percent saturation that is quite acceptable for aquatic organisms.

Test solutions were prepared by adding wet soil (200 ml) and supernatant (800 ml) from the mixing jar to laboratory beakers. There were four replicate beakers for each of three treatments (BV-1, BV-2, and a control). Controls contained 14-ppt salinity seawater with no soil. Ten adult mysids chosen randomly from the laboratory population were added to each beaker. Beakers were set in a water bath held at 25 °C. The mysid bioassay was conducted as an initial 48-hr screening test. There were no water changes during the 48-hr test; mysids were not fed due to the relatively brief exposure period.

Results at 48 hr demonstrated excellent survival. Over 97 percent survival was recorded for the controls and 95 percent for animals exposed to the CAAP soil samples. A few newly hatched mysids were found in the BV-1 and BV-2 beakers, an additional indication of the absence of toxicity associated with these samples. Mysids are routinely used for laboratory bioassays and water quality testing and are recognized as being sensitive to a variety of contaminants (Nimmo and Hamaker 1982, Roberts et al. 1982, Reitsema and Neff 1980).

Penaeus vannamei postlarvae less than 1 cm in length were obtained from Continental

Fisheries, Panama City, FL. They were held at 24 °C and 30-ppt salinity for 5 days before testing. A known volume of soil or sediment was mixed with seawater (1:4 ratio) using methods similar to those described for the mysid bioassay. Test treatments included a control and four samples from the CAAP site: BV-1 from Sites 1 and 2 (Figure 1), BV-3 from Site 3, BV-S from Sites 4 and 5, and BV-6 from Site 6 at the edge of the Brownsville Ship Channel. Postlarvae were also exposed to a moderately contaminated marine sediment (sediment BC-2 in Table 2). This sediment contained relatively high concentrations of metals such as Hg, Cd, Cu, Cr, Pb, and 3.6 ppm total PCB.

The 40-min shaking period and addition of the supernatant to beakers containing soil or sediment did not lower DO concentrations, except for the BC-2 sediment. Water salinities increased after shaking to 32 to 34 ppt and were adjusted back to 30 ppt using 0 ppt water. Each test beaker received 200 ml of wet soil or sediment, approximately 850 ml of supernatant, and 11 postlarvae. Control beakers did not receive soil or sediment. Beakers were placed in a water bath; temperature was held at 26 °C for the 5-day test. This test was run for 5 days (116 hr) because previous sediment tests (Tatem 1988) showed that sediments, in many cases, do not affect test organisms in shorter tests. The test was static, and the animals were fed.

The data (Table 3) clearly show the nontoxic nature of the soil samples from the CAAP site at Brownsville, TX. Both animals exposed to the soil samples revealed survival similar to controls. Thus the bioassay data, plus the data shown in Table 1 for the BV sample, demonstrate the kind of results that would indicate that the DMCA is acceptable for aquaculture. The Brownsville sediment was composed of approximately equal amounts of sand, silt, and clay; in general, the more sand a sediment contains, the less organic carbon and volatile solids and the less contaminants. The three to four metals identified as most toxic by Gambrell, Khalid, and Patrick (1978) (i.e., Hg, Cd, Pb, and Cu) were either very low or within the range of values shown in Table 1 for laboratory reference sediments. The concentrations of PCBs, PAHs, pesticides, and phthalates were below detection limits with the single exception of the phthalate bis(2-ethylhexyl)phthalate, a widespread contaminant associated with plastics. In other words, none of the sediment chemical analysis data suggest anything unusual about these sediments.

Table 3
Survival of *Penaeus vannamei* Postlarvae Exposed to CAAP Soil and BC-2 Sediment

	Survivors, no.		
Treatment	**0 hr**	**48 hr**	**116 hr**
Controls	11	11	11
	11	11	11
	11	11	11
	11	11	10
	11	11	11
BV-1	11		11
	11		10
	11		11
	11		10
	11		11
BV-3	11		11
	11		11
	11		10
	11		10
	11		10
BV-5	11		10
	11		11
	11		11
	11		10
	11		7
BV-6	11		11
	11		10
	11		10
	11		10
	11		11
BC-2	11		11
	11		11
	11		10
	11		11
	11		11

Shrimp samples from the Gulf of Mexico and from the CAAP demonstration farm were analyzed for metals, pesticides, PCBs, and PAHs. These data (Table 4) clearly demonstrate that the shrimp grown at the CAAP demonstration farm, including those grown in Pond B where dredged material from the BSC was deposited during 1987, were uncontaminated and acceptable for human consumption.

Table 4
Chemical Analyses of Shrimp from the CAAP Demonstration Farm, the Gulf of Mexico, and the Brownsville Ship Channel

	Concentration, mg/kg wet wt, ppm					
	BSC	GW	GB	A(87)	B(88)	Method Blank
Metals						
As	1.570	0.690	1.040	0.210	0.350	<0.030
Cd	0.023	0.002	<0.002	<0.002	0.006	<0.002
Cr	5.030	0.050	0.085	0.030	0.050	0.003
Cu	1.780	2.070	10.700	1.810	1.200	<0.150
Pb	0.250	0.020	0.020	<0.005	0.040	0.010
Hg	0.090	0.108	0.074	0.080	0.081	<0.010
Ni	0.025	0.160	0.025	0.020	<0.010	<0.010
Se	0.120	0.170	0.140	0.090	0.150	<0.025
Ag	0.020	0.090	0.060	0.050	0.050	<0.005
Zn	3.750	5.700	5.250	5.900	4.840	0.310
Pesticides[1]						
Aldrin	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
DDT	0.015	<0.002	<0.002	<0.002	<0.002	<0.002
Heptachlor	0.004	<0.002	0.006	0.009	0.004	0.005
Dieldrin	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Chlordane	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Toxaphene	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Polychlorinated Biphenyls						
PCB 1016	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
PCB 1242	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
PCB 1254	<0.002	0.120	0.060	<0.002	0.050	<0.002
PCB 1260	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Polycyclic Aromatic Hydrocarbons[2]						
Fluorene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Phenanthrene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Anthracene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluoranthene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Pyrene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chrysene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

NOTE: BSC = Brownsville Ship Channel; GW = Gulf Whites; GB = Gulf Browns; A(87) = Pond A, 1987; B(88) = Pond B, 1988.

[1] Twenty priority pollutant pesticides were analyzed, with all values (except for DDT and Heptachlor) below the detection limit of 0.002.

[2] Seventeen priority pollutant PAHs were analyzed, with all values (except for phenanthrene) below the detection limit of 0.5.

These shrimp contained very low concentrations of metals, pesticides, and PCBs that were lower than the concentrations found in local wild shrimp. The concentrations of PAHs for the CAAP demonstration farm shrimp were all below the detection limit of 0.5 ppm.

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The Dredging Sponsor's Role, A Case History

by
Richard K. Berry[1]

Introduction

I would like to begin by explaining a little bit about the structure of this specific dredging sponsor. The Brownsville Navigation District of Cameron County, Texas, is a political entity of the State of Texas, organized under Chapter 63, Subchapter C, of Texas Water Code. The District is governed by a Board of five Commissioners, elected at-large from a geographical region in the Southeastern corner of Cameron County, at the extreme southern tip of Texas bordered on two sides by the Gulf of Mexico and the Rio Grande River. Commissioners are elected for four year terms with an election being held each two years.

The District was voted into existence by the Texas Legislature in 1926, with the Port of Brownsville officially opening on May 16, 1936. The Brazos Island Harbor, or Brownsville Ship Channel as we more commonly refer to it, was authorized initially by the Rivers and Harbors Act of July 3, 1930. The Act provided for a 17 mile long channel, extending from the Brazos-Santiago Pass to the turning basin, with a depth of 25 feet and a bottom width of 100 feet. The initial dredging and jetty construction cost a total of $4.1 million.

Since 1936, the channel has been deepened on four separate occasions. Subsequent additions to the Brazos Island Harbor project in 1937, 1945, and 1950 deepened the channel to 31, 33, and its present depth of 36 feet. The Water Resources Act of 1986 authorized deepening to 42 feet. Construction is expected to begin early next year.

Since the inception of the Brownsville Navigation District, its Board of Commissioners has aggressively pursued a land acquisition policy, so that today, the District owns in excess of 40,000 acres of contiguous real estate completely surrounding the Brownsville Ship Channel. Approximately 20,000 acres of the District's land are developable as industrial sites with the balance devoted to wetlands, dredged material disposal sites, and port facilities. The District presently has approximately 2,000 acres of land leased under 250 separate lease contracts. Annually, our leasing operation generates slightly under $2,000,000 in revenue.

I mention my last point to show that Navigation District employees are not neophytes to the business of leasing land. In fact, the Board of Commissioners has approved a written, detailed leasing policy to ensure that all present and prospective tenants are treated equally and the lands are developed in an orderly and environmentally conscious manner.

CAAP Demonstration Project Lease

In January of 1986, the District entered into a lease contract with MARIQUEST, INC., for approximately 125 acres of Navigation District owned land in dredged material disposal area 4E. The lease was for a period of one year and provided for payment to the Navigation District at a lease rental rate of $15 per acre per year, or a total of $1,875. Provisions of the lease allowed for it to be extended for four additional one year terms with the rental increasing each year at a progressive rate until it ultimately reached $60 per acre per year in the last renewal period. Terms of the lease allowed MARIQUEST, INC., to use the land "for aquaculture and

[1] Brownsville Navigation District, Brownsville, TX.

closely related activities as a cooperative project of the U.S. Army Corps of Engineers, the Brownsville Navigation District, and MARIQUEST."

Having had some of MARIQUEST's key personnel as Port tenants since the late 1970's involved with other aquaculture pilot programs, the contractor was very familiar with our rules, ordinances, regulations, and normal operating procedures. Due to the remoteness of the project site, we were not even asked nor expected to provide water and wastewater service, as we normally do for tenants located in our developed areas. Additionally, with the Corps' prior experience in other such projects and wealth of competent, experienced personnel, the joint Containment Area Aquaculture Demonstration Project had very little effect upon the Port's normal activities during the course of the project.

However, upon completion of the demonstration project in late 1989, we were required to embark upon several new, and theretofore time consuming - which for lack of a better name - I will call "exercises." The first exercise involved acquisition of the Corps owned capital assets that had been purchased by MARIQUEST to execute their contract. These assets included several buildings, a portable office built on a mobile home chassis, motor vehicles, several boats and outboards, a tractor with backhoe attachment, several tanks, pumps, and diesel motor generator sets. Due to the relatively short duration of the demonstration project, it had been elected to provide electrical power to run the pump motors with diesel motor generator sets rather than expend the large amount of money the local electric utility, designated by the Texas Public Utility Commission to serve the project site, asked to extend their lines to the remote project site.

Upon completion of the demonstration project, the Corps declared all capital assets that had been purchased for the project surplus for their needs and conducted a complete inventory. The assets were then released to the General Services Administration for disposition. The General Services Administration in turn released the assets to the Texas Surplus Property Agency for disposition through their established program whereby cities, counties, and other public agencies could obtain items declared surplus by both Federal and State agencies.

The Corps of Engineers acquisition cost for the assets was placed at $262,236.94. In late February of 1990, the Navigation District was able to obtain title to the assets by paying $15,104.85 to the Texas Surplus Property Agency. Upon obtaining title, we were then able to proceed with the process of finding a lessee. Speed was of the essence in finding a lessee because once the Navigation District took possession of the assets, it assumed the responsibility for providing security and preventative maintenance for them. We arranged for security and preventative maintenance with the same contractor that the Corps had used for the demonstration project at a cost of approximately $4,000.00 per month. Ultimately, we were required to provide site security for a total of four months at a total cost of almost $16,000.00.

Private Leasing of Site

Having acquired title to the improvements and equipment, our next step was to obtain a lessee. Departing from our normal practice of negotiating lease contracts at established rental rates, we elected to solicit bids to lease the entire facility. It was obvious that the lease contract would have to contain provisions to allow use of the site for dredged material disposal under three conditions, namely:

- Routine channel maintenance dredging.
- Emergency maintenance dredging in the event of a hurricane or other nature disaster.
- Dredging for channel improvement.

For routine channel maintenance and improvement dredging, it was agreed that the Corps could advise the Port who in turn would advise the lessee at least six months in advance of their intended use of the site for

dredged material disposal. Due to limited silting in the Brownsville Ship Channel, the Corps has historically performed maintenance dredging on a four-year cycle. For emergency maintenance dredging, it was agreed that the Corps could give the lessee at least thirty days prior notice of their need to use the disposal area.

After use as a dredged material disposal site, it was recognized that someone would have to reshape the levees and bottom before it could be used again for aquaculture. Again, it was agreed between the Corps and the Navigation District that the lessee would, under the terms of the lease, assume this responsibility. During those periods of time when the Corps was using the site for placement of dredged material, the lease contract abated both land lease and equipment rental payment, but still held the tenant responsible for maintenance and safeguarding of the equipment.

To comply with the Port's equipment acquisition agreement with the Texas Surplus Property Agency, who in turn was obligated by their equipment acquisition agreement with the General Services Administration, our lease agreement required that the lessee provide the Corps of Engineers with production and cost data during the first two years of operation. The lease also required that the lessee provide the Texas Surplus Property Agency with payroll and employment data during the same two year period.

Additional special provisions of our lease agreement allowed the lessee, upon completion of the primary term of the lease, to purchase the equipment from the Port at a mutually agreed upon price. The primary term of the lease was set at a minimum of two and a maximum of five years to comply with a requirement of the Texas Surplus Property Agency that stipulates the recipient of surplus property must retain title to and use the property for at least two years before they are free to sell it. After expiration of the primary term, the lease allowed the lessee, at his discretion, a maximum of four renewal options with a minimum duration of two and a maximum duration of five years.

Land rental rates at the Port are set by our Board approved leasing policy at ten percent of the appraised value of the land. For instance, if we lease property that is appraised at $10,000 per acre, our policy requires that we rent that property for $1,000 per acre per year. Our appraisals are re-evaluated each five years by a panel of local realtors. A provision of our standard lease contract provides for resolution of a disputed re-evaluation by a panel of three appraisers, one selected by each party and the third selected by those two. I mention this because another provision of the lease for the shrimp farm allowed for re-evaluation at the end of the primary term and each renewal option.

From the previous discussion regarding the special provisions of the draft lease that was included in our bid package, one can see that it was necessary to prepare a document that satisfied not only the Port's needs, but also those of the Corps of Engineers and the Texas Surplus Property Agency, all the time keeping in mind the fact that the lease could not be so restrictive that it would not allow a potential lessee the freedom needed to operate the shrimp farm on a profitable basis. Judging from the ultimate response to our acceptance of bids, perhaps we did not do too good a job in this respect.

The Corps' Waterway Experiment Station was extremely helpful in publicizing the fact that there was a shrimp farm for lease by the Port in Brownsville, Texas. They prepared news releases and arranged for their publication in various trade journals and provided production and cost data for enclosure with the bid package that was sent out in response to inquiries. The initial response to the news release was very encouraging. Requests for information were received from as far away as Alaska and China. However, when it became time to open the bids, only one was received.

The one bid that was received was placed by a company by the name of VIC International

out of Alhambra, California. VIC's bid offered to pay an annual land rental of $4,000 and an annual equipment rental of $18,000, for a total annual rental of $24,000. VIC's bid requested the minimum acceptable primary term of two years and four renewal options of five years each. Such a lease was prepared and sent to VIC International for execution on May 18, 1990. The lease, which became effective on June 1, 1990, was eventually executed by VIC on June 20, 1990, and returned along with their check for the first year's land and equipment rental and the required $6,000 security deposit.

I failed to mention the fact that our established leasing policy requires that the lessee provide a security deposit equivalent to three months rent. The security deposit is to be used for site clean up or equipment repair in the event that a lessee defaults before expiration of the primary term and does not comply with the provisions of the lease in those specific areas. This provision was added in the late 1990's as a result of several bad experiences with lessees that defaulted on their leases. Over the years, we have noted that the majority of lease defaults occur during the primary term. More recently, we have been accepting Certificates of Deposit as security, made payable to the lessor with interest payable to the lessee.

An additional standard lease requirement that I failed to previously mention pertains to liability insurance. We normally require our lessees to carry, in addition to statutory Workmen's Compensation insurance, a minimum of $1,000,000 of comprehensive general and comprehensive automobile liability coverage. In the case of our shrimp farm lessee, VIC International, we have never received, despite numerous phone and written requests, a certificate of insurance.

Although VIC International eventually executed the lease, paid the first years rental in advance, and provided a security deposit equal to three months rent, they never made any positive attempt to put the farm into operation during the first year of the lease. At the end of the first year, the lease was canceled for non-payment of the second year's annual lease rental. At the present time, our Director of Industrial Development and Leasing Manager are actively looking for a new lessee and already have had conversations with several interested parties. We do not intend to accept bids on the site a second time, but rather, to handle the shrimp farm as we do all of our other properties by negotiating a lease contract with the first prospect that executes a lease application that is acceptable to our Board of Commissioners.

Recommendations

In retrospect, looking back at what we did right and wrong, I have serious reservations about the propriety of and legal requirement for accepting closed competitive bids on the site. In preparing the rigorous set of lease conditions that all bidders would be afforded equal treatment, we left very little room for interested parties to negotiate changes to restrictive clauses that would have made it impossible for them to conduct a successful business. While we are required by our agreement with the Texas Surplus Property Agency and the fact that the primary use of the site is for the placement of dredged material to include certain restrictions in the lease contract, there are still certain of our own internal restrictions that were placed in the contract. Some of these are subject to negotiation. In fact, it is even possible that some of the restrictions that were agreed upon with the Corps of Engineers pertaining to the use of the site for dredged material disposal could be modified through negotiations to accommodate a prospective lessee's needs.

One of our infrequent contacts with the principal of VIC International was when he was inquiring about a right-of-way for the local electrical utility to provide electrical service to the site. This points out what I consider to be the major detraction from using this particular dredged material disposal site for an aquaculture project; the non-availability of utilities at the site. The dredged material disposal site we

leased to VIC International is typical of many, because of its remote location. Prospective users of such sites should take into consideration the major capital investment in equipment, the high operating costs, and the extensive equipment maintenance required to generate the electricity needed to operate necessary pumps and other equipment. This is something I am sure VIC International realized too late. The availability of utilities should be a major consideration when selecting a dredged material disposal site for an aquaculture project.

Legal and Contractual Relationships[1]

by

Sylvia Robertshaw[2]

Abstract

When those responsible for maintaining the nations waterways turn their attention towards upland disposal areas, they face increasing difficulties acquiring adequate disposal space for their dredged material, particularly in coastal areas, for several additional reasons:

- *Dredging project sponsors have to compete with more profitable and more attractive surface uses when trying to persuade private landowners to grant them disposal easements.*
- *Dredged material disposal is perceived by the public as waste disposal.*
- *Leases or easements tend to tie the land up for long periods of time.*

These difficulties have led the Corps to search for innovative ways to help secure and retain access to real property suitable for upland Dredged Material Containment Areas (DMCAs). The Corps has funded research into possible beneficial uses for DMCAs, and the Containment Area Aquaculture Program (CAAP) constitutes one outgrowth of that research.

Among the beneficial surface uses that the Corps has considered to assist in the acquisition and retention of disposal sites is the operation of an aquaculture facility. The CAAP grew out of these concerns for the continued availability of confined disposal space for the Corps' ongoing dredged material disposal needs. As has been explained in the other technical reports in this series, the main purpose of the CAAP is to demonstrate the technical and economic feasibility of the concept of containment area aquaculture. It is hoped that the CAAP will facilitate the ability of the Corps and the local sponsor to secure additional acreage for new on-land DMCA sites by making them more competitive, vis-a-vis other potential parties seeking land in coastal areas. Landowners would potentially receive both easement payments from the Corps and local sponsors, rental payments from the aquaculturist, and enjoy the benefit of capital improvements on their property mad by the Corps. This promise of greater revenues from their property (from the increased property value from the improvements and/or the lease payments) will make the Corps and local sponsors more competitive in the market for land uses, particularly in coastal areas.

[1] This presentation was based on information from the following publications: Legal And Institutional Constraints On Aquaculture In Dredged Material Containment Areas by Sylvia Robertshaw, Richard J. McLaughlin, and Donald Love. Technical Report EL-93-7, U.S. Army Engineer Waterways Experimetn Station, Vicksburg, MS.

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Part One of the legal technical report consists of three chapters and is designed as an overview of the laws and regulations that may apply to the creation and operation of a CAAP. The material is organized into two chapters on the disposal of dredged material by the Corps (Chapter One covers federal and Chapter Two covers state) and one chapter on the aquaculture operation. These chapters are designed to outline the laws, regulations, and permit requirements that may apply when a CAAP is established. State regulations are covered for the following six model states: Alabama, Florida, Louisiana, Maryland, South Carolina, and Texas. These model states were selected because: (1) they represent a variety of regulatory environments; (2) confined disposal of dredged material is already practiced there and it is anticipated that additional DMCA will be needed in the future; and (3) aquaculture is a significant industry.

Part Two of this Technical Report addresses the legal issues that may be raised by containment area aquaculture. These legal questions are often novel questions since dredged material disposal and aquaculture have not taken place on the same site in the past—usually the two functions occur in separate and distinct areas. Chapter Four discusses potential issues, and Chapter Five makes suggestions for drafting the documents involved in a CAAP to accommodate the special circumstances created when the two functions coincide.

Permit and Review Process

by
Cynthia Wood[1]

Introduction

If a proposed aquaculture site is located within an authorized Corps of Engineers (CE) containment area, a separate Section 10 and/or Section 404 permit would not be required. Although the proposed work within a Corps containment area would go through a similar review process, the findings are discussed in environmental documents prepared in conjunction with the Federal project. If an individual proposes to construct an aquaculture site not located or associated with a Corps Federal project or if modifications to an existing site are proposed which were not covered in previous environmental documents, an individual permit would be required. The following describes the regulatory program and the permit process.

Background

The Department of the Army Regulatory Program is one of the oldest in the Federal Government. Initially, it served a fairly simply, straightforward purpose: to protect and maintain the navigable capacity of the nation's waters. However, changing public needs, environmental awareness, and new statutory mandates have drastically changed the regulatory program broadening our authority and our mission. We now consider numerous public interest factors in our permit decisions including wetland concerns.

The Galveston District has received several permit applications for aquaculture projects within the past few years. The majority of these have been for Section 10 authorization for intake and outfall structures and dredging. In some cases, a nationwide permit was issued if only an outfall structure was required. A Section 404 permit is required if the proposed work requires the placement of any dredged or fill materials in waters of the United States. To understand the laws involved and when a permit is required, a brief discussion of the placement of the regulatory program is provided.

Legislative Authorities

The U.S. Army Corps of Engineers (USACE) has been delegated authority by Congress to regulate construction activities on waters and wetlands. The Corps has jurisdiction under two separate but related laws: Section 10 of the River and Harbor Act of 1899 (R&HA) and Section 404 of the Clean Water Act. A detailed explanation of the Corps Regulatory Program was published in the Federal Register on November 13, 1986, Part II.

Section 10 of the Rivers and Harbors Act

This act was enacted to protect navigation and the navigable capacity of the country's waters. Navigable waters as those waters subject to the ebb and flow of the tide and/or presently used, or have been used in the past, or may be susceptible to use in the future for transport of interstate and foreign commerce. Section 10 of the R&HA (33 U.S.C. 403) requires a permit for structures and works in navigable waters. Examples of activities requiring a Section 10 permit are: piers, intake structures, bulkheads, pipelines, dredging, channelization, and oil/gas production activities in navigable waters of the United States.

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[1] U.S. Army Engineer District, Galveston; Galveston, TX.

Section 404 of the Clean Water Act

In 1972, Congress enacted the Federal Water Pollution Control Act (FWPCA) which was later amended in 1977 as Section 404 of the Clean Water Act (33 U.S.C. 1344). The purpose of the Act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Section 404 established a permit program, administered by the Secretary of the Army, acting through the Chief of Engineers, to regulate the discharge and disposal of dredged and fill material within the waters of the United States which include wetlands.

Wetlands

Federal regulations define wetlands as those areas that are inundated or saturated often enough to support a prevalence of vegetation adapted for life in saturated soil. Unfortunately, for many years wetlands were viewed as undesirable areas and, therefore, readily used as prime sites for landfills and commercial and residential development. Now, however, we know that wetlands play several significant roles in preserving the quality of the human environment. The 404 permit program is designed to preserve the numerous wetland functions such as flood control, erosion and storm damage prevention, water purification, wildlife habitat, and food production necessary to support juvenile shrimp, sportfish, and migratory water fowl.

Aquaculture activities which normally require a Section 404 permit include levees, placement of dredged material in waters of the United States, backfilling of bulkheads, and/or filling for road access.

Jurisdictional Determinations

For work proposed in navigable waters, the need for a Section 10 and/or 404 permit is straightforward, and normally the process begins with receipt of an application. However, for work in wetlands, the process may begin with a request for a Corps wetland delineation. The Corps and U.S. Environmental Protection Agency (EPA) are responsible for making wetland delineations which involves using the multiparameter approach of examining the vegetation, soils, and hydrology. The Federal manual for identifying and delineating jurisdictional wetlands was developed by the Corps, EPA, U.S. Fish and Wildlife Service, and the Soil Conservation Service. Due to the number of wetland delineation requests we receive, there is a turn around time of several months. Therefore, if time constraints are a factor for a potential applicant, he may elect to hire a private consultant who is familiar with the Federal manual to perform the wetland delineation. Although we still need to confirm its accuracy, the information and field data provided by the consultant using the new wetland manual will reduce our turn around time.

The Permit Evaluation Process for Individual Permits

Once an application is submitted, it is first assigned a number for reference purposes. The application is then reviewed for completeness. If it is not complete, we will contact the applicant by phone or letter for the information needed. Once we receive a complete application, we will often coordinate it with the various Federal and State resource agencies during our biweekly evaluation meetings to get their initial input and recommendations. Often potential problems can either be identified or resolved at this time. The U.S. Fish and Wildlife Service early in the process indicate their standard recommendations concerning aquaculture projects which consists of the following items:

- Entrainment and impingement of macrofauna shall be prevented by utilizing intake screen mesh openings of not more than 0.5 mm and intake water velocities of not more that 0.5 ft/sec at the intake screen interface, which shall be located between the estuary and any pumping device. Alternate designs must be approved by the resource agencies.

- Any biocides used shall be approved by the resource agencies.
- Any biocides used shall be stored in a manner to prevent any accidental release.
- Distribution of biocides into ponds (in case of a natural disaster) shall be included in the system design.
- Temperature of the water at the outfall device shall not deviated from ambient by more than 2 °C.
- Dissolved oxygen content of the water at the outfall device shall be greater than or equal to 4 parts per million.
- Salinity of the water at the outfall device shall not deviate from ambient by more than 5 parts per thousand.
- Mariculture discharge shall not exceed 0.5 ft/sec in or near vegetated wetlands.
- All ponds and levees shall be constructed on upland locations.
- No dredging or filling (including scouring, shoaling, and propwashing) shall occur within 25 ft of vegetated wetlands.
- Water usage shall be of at least 50 percent recirculated water.

The public notice is then prepared. The public notice is our primary means of advising interested parties of the project and of soliciting comments and information to assist us in evaluating the impacts of the project on the public interest. The public notice comment period is normally 30 days, but may be reduced to 15 days for those projects expected to be noncontroversial. Either length may be extended, if warranted. Public notices are distributed to all known interested parties including local, state, and federal agencies, adjacent property owners, and interested individuals and groups. Any person or group may submit written comments on proposed projects. These comments will be considered in the decision. If objections cannot be resolved, the applicant may submit a rebuttal and request a decision from the District Engineer.

The District Engineer will then evaluate the data, environmental impacts, and comments received and make a decision based on public interest to approve, modify or deny the permit application.

The decision to issue or deny a permit is based on a public interest review which takes into consideration a full range of public interest factors. These factors include navigation, safety, economics, conservation, aesthetics, recreation, land use, water quality, food plain values, energy needs, cultural values, mineral needs, water supply and conservation, shore erosion and accretion, fish and wildlife values, food and fiber production, safety, wetlands, general environmental concerns, and the need and welfare of the public. When a Section 404 activity is proposed, the District Engineer must determine if the work is in compliance with the 404 (b) (1) guidelines. The most stringent fill material can be permitted if there exists a less environmentally damaging alternative to the discharge which would have less adverse impact on the aquatic ecosystem. For an alternative to be considered practicable, it must be available and capable of being done after taking into consideration cost, existing technology, and logistics in light of the overall project purpose.

The normal evaluation process takes approximately 60 days for noncontroversial permits and longer for controversial permits, due to the likelihood of public hearings, Environmental Impact Statement preparations, Section 7 Consultation for impacts to threatened and endangered species, cultural resource coordination, etc.

If the decision is to issue the permit, two copies of the permit document are forwarded to the applicant for his signature, an indication that he accepts the terms and conditions of the permit. There is a permit fee of $100.00 for commercial work, $10.00 for noncommercial; however, these amounts are presently being proposed for change. If the permit is denied, the applicant will be informed in writing of the reasons for denial.

Modification, Extensions of Time, Transfers

After a permit has been issued, any change to the original permitted plans needs to be submitted to our office. Depending on the extent of the change, an administrative modification may be possible; otherwise, re-evaluation may be required. Normally, permits are valid for three years. If additional time is needed, a request to extend the time to complete the work should be received by us at least 3 months before the permit actually expires.

Also important to note on the permit is the requirement to notify us when the work is completed and if the permit has been transferred. The simplest way to transfer a permit is to have the transferee sign in the space provided on the original permit and submit it to us. Receiving information from the permittee on the status of the work authorized assists us in maintaining accurate permit records.

General Permits and Nationwides

So far all reference to permits has been for individual permit authorizations. The Corps also issues other types of permits. The nationwide permits authorize certain types of work which meet specific requirements throughout the nation and are designed to allow work to occur with little delay and paperwork. One nationwide permit used by those in the aquaculture business is Nationwide #7 which authorizes outfall structures. Presently, there are 26 nationwide permits, but the new regulations presently under review contain over 40. The nationwide permits can be found in the aforementioned Federal Register.

At the Galveston District level, we have issued several general/regional permits for structures or projects that are similar in nature and cumulatively will have only minimal adverse effects on the environment. These permits are designed to streamline administrative procedures for the simpler, less controversial projects. A copy of all our general permits can be obtained upon request.

Enforcement

For the permit evaluation process to work smoothly, it is best to evaluate a proposal before any work begins. Unfortunately, we must contend with unauthorized activities. Reports of unauthorized work are received from the public, other agencies or by surveillance. If necessary, we issue a cease and desist order. We may require restoration immediately or accept an after-the-fact permit. Violations of Section 404 can result in both criminal and civil penalties which can be severe.

Other Issues

Although we have not received any official regulatory guidance yet, President Bush's "No Net Loss" statement regarding wetlands has affected our evaluation of Section 404 permits.

A recent Memorandum of Agreement (MOA) with EPA, which attempts to meet this no net loss goal, stresses mitigation sequence of avoidance of impacts, minimization of impacts, and lastly compensation of unavoidable impacts through restoration or wetland development. The MOA requires that we first thoroughly consider alternatives to the project which would avoid any wetland impacts. Should no practicable alternative exist, we then must attempt to minimize the impacts to the maximum extent possible. After we are satisfied that all attempts have been made to avoid and minimize the wetland impacts, compensation through mitigation will then be considered to offset the unavoidable impacts of the proposed project. Most compensatory mitigation involves the creation of new habitat to replace that being impacted. It is preferred that mitigation be performed in close proximity to the proposed project, preferably on-site. Since this is not always feasible, off-site mitigation may be considered. Other types of compensatory mitigation include mitigation banking and preservation. Mitigation banking is gaining more acceptance; however, preservation as compensation is usually not accepted unless it can be clearly shown that it is a high value habitat which is not protected under any regulations.

Revised regulations and new nationwides are currently under review. Wetland delineation manual is also under revision.

The regulatory program is continually changing. With increasing environmental consciousness among all groups and a cooperating effort, the future of the program will continue to ensure a balance between our country's economic needs and the conservation of our natural resources.

DMCA Design and Operations

by
Herbie A. Maurer[1]

Introduction

The Galveston District maintains approximately 1,000 miles of navigation channel (760 miles—shallow draft; 240 miles—deep draft). The Corps of Engineers maintains 25,000 miles nationwide.

Maintenance of these navigation channels requires the removal of approximately 30 to 40 million cu yd of shoal material from the Galveston District with approximately 300 million cu yd nationwide. A history of shoaling within each navigation channel is maintained for predicting future maintenance requirements.

Maintenance is performed by dredging to restore the navigable width and depth of the channel. There are many types of dredges; however, the most two common types are (1) hopper and (2) pipeline cutterhead. The hopper dredges are normally used to maintain entrance channels located in an open sea condition. The pipeline cutter dredge is utilized basically inland within a protected sea condition. The hopper transports the shoal sediments to designated sites offshore if the material is not utilized beneficially, i.e., to feed shoreline beaches, or construct a mound. The pipeline cutterhead dredge pumps the material through a pipeline to a designated area. The dredged material may be utilized as a beneficial use within an estuarine system. If no beneficial use is available for the dredged material, the material is placed within a confined area.

What is a Dredge Material Containment Area (DMCA)? A typical DMCA may be described as a leveed upland area consisting of between 100 acres to 1,000 acres for the placement of material removed from the navigation channel. The area will contain a water control structure to decant the water from the sediments. The sediments are tested before dredging operations commence and determined clean material before placement into the DMCA. Hazard toxic waste are treated in a special manner and consist of a very small portion of material removed annually. These special DMCAs would not be offered for Containment Area Aquaculture Projects (CAAP).

Design

Design and sizes of the DMCA are dependent on the amount of material to be placed into it over a period of its life (up to 50-year life). The volume of material is estimated from the shoaling history of an adjacent reach of the navigation project. The characteristics of the material will determine a bulking factor to compute the actual volume to be occupied within the DMCA. A technical design manual is available to assist in determining the amount of volume required in the DMCA to achieve an acceptable water quality at the decanting water control structure. Generally, a rule of thumb provides for an elevation 3 additional ft above the material volume (2-ft ponding plus 1-ft freeboard).

Foundation conditions and type soils will determine the final levee section design. Within the Galveston District, a 10-ft crown with 1 on 3 side slopes is generally sufficient in clay type soils. Levees are generally constructed for the particular dredging contract and raised accordingly for future contracts.

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[1] U.S. Army Engineer District, Galveston; Galveston, TX.

Operations

Operational aspects of the DMCA consist of placement of the material in the area in a manner to achieve maximum utilization of capacity and to meet water quality as decanted water is released over the weir section of the water-control structure. The weir is raised by placing boards within the structure accordingly as dictated by water quality test readings. Water quality requirement generally require to be within a range of 8 gm/ltr over the receiving body of water.

The DMCA is managed between dredging cycles. The shoaling history of the navigation channel determines the dredging cycle (the period of time between dredging cycles). Management consists of dewatering the surface followed by intensive dewatering of the subsurface. This dewatered dredged material is considered restoring volume to the DMCA. Any remaining time in the off cycle may be utilized for beneficial use concepts such as CAAP.

The Effects of Dual Use DMCA as a CAAP

Positives	Negatives
Provide additional real estate needed for placement of dredge material. Reduce local sponsors' cost for providing real estate for the project. Provide incentive to land owner to donate land since levees and harvest structure will exist for CAAP. Increased income for land owner where land is marginal. DMCA covered under project Environmental Statements.	Scheduling of dredge. Period of no stocking during year of dredging & construction. Providing additional capacity in advance of dredging for CAAP. Minimizes management time of dredged material. CAAP operations, requires appropriate permits by grower. Owner to provide additional equipment for H_20 exchange.

Design and Construction of Aquaculture Facilities

by
Claude Mehaffey[1]

Introduction

I first became interested in aquaculture when I was still in high school. My oldest brother came back from World War II and decided to go into the business of raising minnows. Since we lived close to Possum Kingdom Lake in North Central Texas, it seemed like the logical place to raise minnows especially since Possum Kingdom Lake was one of the largest and hottest fishing lakes in Texas at that time.

If enthusiasm could make someone rich, my brother would be a multi-millionaire. Just think of it, those minnows would lay eggs by the thousands and he would sell them by the dozen. (I'll bet that sounds familiar to some of you.)

Anyway, my brother bought a few acres on the lake, fixed up an old school bus to live in, and went to work with a farm tractor and a blade that he borrowed from my father. I spent several weekends helping him with equal enthusiasm especially since he was a war veteran and a hero in my eyes.

Actually, everything went very well. The ponds were being built in a good sandy soil. After the ponds were built, we installed a pump just outside the ponds and began pumping water from the lake. After that, it was just a matter of getting the brood minnows and feeding them. My brother soon found out that black bass were very efficient predators. He soon had one or two nice size bass in each pond and no minnows. Still no problem. He would filter the water more carefully and start over with some more brood minnows.

It was about this time that a problem began to surface. As soon as the pump was shut off, the ponds would begin drying up in a hurry. As the water level in the lake receded, the more difficult it was to keep water in the ponds.

To make a long story short, my brother eventually went broke pumping water. However, it wasn't a loss. Someone else came along, bought the ponds, and proceeded to go into the same business. It wasn't long until he sold it to someone else who sold it to someone else who sold it to someone else until the whole project was abandoned.

My brother decided raising worms would be easier, and I decided to try playing college football. After graduating from college, I went to work for the Soil Conservation Service (SCS).

My next interest in aquaculture came in the 1960's when so many people decided to go into the catfish business. During this time, the SCS began a training program on everything from soil suitability, to pond construction, to management and marketing. We visited lots of catfish farms but many of them did not seem prosperous. Therefore, when someone would come to me for assistance, my first impulse was to discourage it until they visited some catfish farms. That would usually be the last I would hear about it.

Site Selection

If you were to ask me what were the three most important things to look for in aquaculture, I would tell you: site selection, site selection, and site selection.

[1] Aquaculture Consultant, Rio Hondo, TX.

For my presentation, let's assume that we have an ample supply of quality water and a suitable climate. The first thing we want to look at is the soil. I don't know whether you believe that God created the earth or whether it just happened. I just know that there are limitations. My brother found this out the hard way and constructed on a soil that had severe limitations. To me, a pretty good definition of a severe limitation would be a one-legged man in a kicking contest. He can do it, but he must be willing to pay the price, and he has to pay the price every time he kicks. It has been my experience that he will try to get someone else to do the kicking, or he will eventually give it up.

The point I'm making is that if you are not familiar with soils, go find someone who is, and let that person examine the proposed site and determine soil suitability. In this area, for example, we often find 3 to 6 ft of clayey material over a saturated sand or water table. If we know this, we know that we must avoid deep excavation. If we excavate into the water table, the pond will probably seep horizontally and surface on your neighbors property.

Other things to look for in site selection is a manageable slope and enough elevation to allow adequate drainage. In this area, we also need enough elevation to stay out of trouble with storms.

After determining that the site is suitable, the next thing that we want to do is prepare a map of the area that not only shows the dimensions of the area but the elevation on a grid of 100 ft by 100 ft. We simply take an elevation shot on each 100-ft stake. This may not seem too important on flat land, but it is important in designing the water delivery system, drainage, and most of all, the excavation for the pond levees. During the design process, the grid or elevation map also becomes our plan map. It just gives us another dimension to go by in planning. It's just not enough to draw lines where the facility is going to be—We want to be able to read the elevation so that we will know that the ponds will drain, the water delivery system will deliver water to it's final destination, and the plumbing can be installed at the exact elevation before construction begins. It is at this time that we want to work very closely with the decision maker. We want to know what he wants, and we want him to know what we are doing. After all the layout has been agreed to, it is time to start construction.

Pond Construction

The first thing to install is the drainage system, at least to the first pond. You must have some way to get rid of excessive rainfall during construction since nearly any rainfall during construction is excessive. Next, install the drain pipe at a predetermined depth. I have observed the installation of the drain pipe by cutting the levee. This is an unnecessary expense and it weakens the levee.

Before constructing the levee, the site should be prepared by removing all vegetation and possibly plowing, removing topsoil or core trenching, and back filling. The extent differs from one soil to the other, but I can almost guarantee that seepage will occur under the levee if nothing is done. As a matter of fact, I have just finished designing a drain line to intercept seepage water from existing ponds. This is being installed after some 50 acres were salted out on the neighbor's property. It may yet wind up in a lawsuit, and it was all unnecessary.

Constructing ponds is not just building levees to impound water. I design the pond bottom at the same time I design the levee. I simply balance the excavation with the fill needed to complete the levee. This way, the bottom is shaped to drain at a specific point and at a specific depth, the same depth where we have previously installed the drain. This also allows the use of the drain pipe to remove excess rainfall during construction. I compute the yardage in the same manner that I would design land leveling for irrigation. By knowing the elevation of each point on the grid sheet, I just determine the cut needed, to achieve the desired slope of the bottom so that water will flow to the outlet when the

pond is drained. The use of laser grade control equipment by the contractor really helps. In fact, I believe it is cheaper to construct ponds this way, and it is so much more precise. No one wants pot holes left in the bottom of the pond.

The design of the levee should allow for the eventual wave action erosion. I am not sure that this erosion can be prevented on ponds of any size especially where salt water prevents protective vegetative growth. Erosion is more easily controlled on fresh water ponds. However, we try to prevent erosion by constructing a flatter slope on the inside of the pond.

In this area, we have strong prevailing wind from the southeast to the northwest, especially during the time that ponds are full of water. The south and east banks of the inside of the pond are much less likely to cause a problem, so I might design a 2:1 inside slope on those levees. The north and west slopes really take a beating so I will design slopes on 3:1 or flatter, depending on the area of the pond. This also allows dirt moving equipment to travel horizontally for better compaction. For instance, a north to south inside levee that has water on both sides may have a 3 or 4:1 slope on the east and a 2:1 slope on the west side.

The top width should be enough to allow for the use of whatever vehicles the operator uses and then some. It does not cost much to add width at the beginning. It gets expensive and much more difficult the second time.

In closing, I would like to give credit to the agency where I worked for over 30 years. The SCS is so dedicated to training. In the construction of aquaculture containment facilities, a person needs a little knowledge of soils, drainage, water delivery, land leveling, pipeline design, pond design, and yardage computations, along with a little common sense. As an employee with the SCS in nine different locations, I was able to get training in all of these disciplines except the common sense part. Hopefully, I had a little bit of that to start with; sometimes I wonder.

Design and Construction of the CAAP, Shrimp Farm Demonstration Project

by
Durwood M. Dugger[1]

Introduction

The United Nations expects the world population to grow from its current 5.25 billion to 6.13 billion by the year 2,000. Each year the world population will increase by an average of 86 million people. This growth rate will cause the world population to double in 40 to 50 years. In the United States, the annual population increase is equivalent to adding another city the size of Los Angeles. This surge in world population growth has had a dramatic impact on the world's food and land resources, their respective production, and use. Nations, once self-sufficient food producers, now have become major importers of much of their food needs. Seafoods, which have been traditionally almost totally wild caught, have been most affected. Stocks of high value and highly sought after seafoods in many cases have been fished to extinction. The United States now imports more than 68 percent of the fish sold through retail outlets.

World per-capita seafood consumption is projected to grow from its present 27.3 lb (live weight) to 34 lb by the year 2000. This means the world seafood supply will have to nearly double in the next nine years from today's 63.5 million tons to 94.5 million tons. This remarkable seafood demand increase of 31 million metric tons, is more than the current total commercial seafood production of Japan, the Soviet Union, and the United States combined. Aquaculture appears to be the only solution to make up the shortfall between the seas inability to produce more and man's ever growing requirements for seafood.

In the United States, important aquaculture industries exist for oysters, clams, crayfish, catfish, trout, baitfish, and ornamental fish. Shrimp farming, which is rapidly expanding internationally, has lagged behind in domestic development. This is partly due to high costs of construction and lack of suitable and permitable sites. The United States imports over 90 percent of its edible seafood and about 45 percent of imported shrimp are farm produced.

Population growth in the United States has also had a dramatic impact on land use, creating a highly competitive environment for the acquisition of almost any land. Reacting to this increased competition public and private land use competitors are re-examining traditional methods for which they have used land in order to use their required land resources more efficiently. Two such competitors are the U.S. Army Corps of Engineers (USACE) and the U.S. aquaculture industry.

The USACE is charged with the responsibility of maintaining all of the navigable waterways of the United States. To accomplish its maintenance mission, approximately 300 million cu yd of sediment are dredged annually by the USACE. Much of this material is placed in dredged material containment areas (DMCAs) which are diminishing in number each year as they fill to their practical capacity (Engler, Patin, and Theriot 1988). Although DMCAs often have a usable life span of up to 50 years, an estimated 7,000 acres of new DMCAs are needed annually. Most DMCAs are located on private land, and acquisition of easements for placement is the responsibility

[1] Cultured Seafood Group, Inc., Laguna Vista, TX.

of the dredging project sponsors. Acquisition is difficult because of high real estate values, the long-term nature of the easements, and the perception by land owners that dredged material is not aesthetic.

To overcome these difficulties the USACE has worked to develop beneficial use concepts that identify ways in which the landowner can use the acreage for activities that are financially attractive but do not interfere with periodic placement of dredged material. The Environmental Laboratory of the U.S. Army Engineer Waterways Experiment Station (WES) conducted the Dredged Material Research Program (DMRP) from 1973 through 1978. One of the specific goals of the DMRP was to "develop and test concepts for using placement sites for productive purposes and consider the use of dredged material as a natural resource" (Saucier et al. 1978). Two work units funded under the DMRP that addressed productive dredged material uses were: The Investigation of Mariculture as an Alternative Use of Dredged Material Containment Areas and The Demonstration of Marine Shrimp Culture in an Active Dredged Material Containment Area. Important results from these two investigations included:

- The identification of 400 species of plants and animals with culture potential in DMCAs.
- Pilot scale shrimp cultivation studies in dredged sediments revealed no biological limitations for the mariculture of this species.

Other studies helped confirm potential for aquaculture in DMCAs. For example, most potential contaminants likely to be found in dredged material were found to be tightly bound to the sediments and were not accumulated by the shrimp being cultivated over them (Quick and Morris 1976, Tatem 1983).

The USACE recognized aquaculture's compatibility with dredged material placement activities because aquaculture ponds and DMCAs share many design characteristics. Common features include perimeter levees to retain water, construction on relatively impervious soils, and control structures for water discharge and drainage. Both facilities have similar regulatory and permitting requirements for construction and operation. Also both types of facilities include locations adjacent to waterways in coastal areas, often on large tracts of land and near transportation routes or major markets. These characteristics, and the positive results from the initial studies, led the USACE to create the Containment Area Aquaculture Program (CAAP) to examine fully the beneficial use concept of aquaculture as a tool for the acquisition of future DMCAs.

The marine shrimp was chosen over other aquaculture candidate species for the CAAP's first demonstration project because:

- Its preliminary studies had indicated that shrimp grew well in experimental ponds in which dredged material had been placed.
- Technical improvements in shrimp hatchery operations made in the early 1980's reduced the cost of postlarval shrimp needed to stock ponds from over $40 per thousand shrimp to about $12 per thousand, making the growout of marine shrimp more profitable.
- A sufficiently broad culture technology had developed that allowed the rapid expansion of large scale commercial shrimp farming in over 40 countries.
- A historically high value and unsatisfied U.S. market for marine shrimp.

Motivating Forces and Potential Benefits

The primary benefit of aquaculture use of DMCAs is improved ability to acquire new placement sites. Significant benefits can also be realized from DMCA aquaculture by the aquaculture industry, port and waterway interests, and land owners. High costs for land, construction, and restrictive legal and regulatory

requirements have hindered the development of pond-based coastal aquaculture in the United States. Thus, prospective aquaculturists will benefit from increased availability of suitable sites for pond culture and reduction of certain site development and construction costs. The waterway interests and dredging industry will benefit from increased availability of needed real estate for DMCAs. Land owners will benefit from site improvements, enhanced land value, and from a greater return from their land as operational income or lease fees. Finally, the local economy will be enhanced by the introduction of a new industry, and the national economy by replacement of imported seafood with a local product.

Containment Area Aquaculture Program

To demonstrate the feasibility of DMCA aquaculture, the USACE conducted a three-year project to grow penaeid (marine) shrimp in two active DMCA's near Brownsville, Texas. The program was conducted with funding support from the Operations and Readiness Division in the Directorate of Civil Works of the Office of the Chief of Engineers (OCE) and done in cooperation with the Construction-Operations Division of the Galveston District. On site management was provided initially under contract by MariQuest, Inc. and later completed by Cultured Seafood Group, Inc. (CSG). CSG specializes in the design, construction, management, and operations of commercial shrimp production systems. Overall CAAP administration was provided by personnel from WES and overseen by a field review committee that included representatives of the Operations and Readiness Division, Directorate of Research and Development, Dredging Division of the Water Resources Support Center, the Southwestern Division, and Operations and Maintenance personnel from U.S. Army Engineer Districts in Mobile, Baltimore, Charleston, and Galveston.

Program Objectives

The purpose of the demonstration project was to establish, for both the USACE and the aquaculture industry, the economic and technical feasibility of containment area aquaculture. From the USACE perspective, feasibility requires the demonstrated ability of aquaculture operations to coexist with dredged material placement, the primary function of DMCAs. It is important to recognize that the application of the concept is preferably to acquire new DMCA sites and not to convert existing DMCA sites to aquaculture use.

Specific objectives of the CAAP Shrimp Farm Demonstration Project included the following:

- Determination of design specifications and construction methods that would allow multiple use of DMCA for both aquaculture and dredged material placement.
- Development of management strategies that allow aquaculture operations and material placement to coexist.
- Documentation of construction and operation costs to allow an objective evaluation of economic success.
- Compilation of the economic and technical information generated by the project into a series of information transfer documents that will outline the general guidelines and specific procedures for the construction and operation of a containment area aquaculture facility.

Selection of the CAAP Demonstration Site

A number of sites were initially selected in various coastal states as possible locations for the CAAP demonstration. Texas was identified as the state that provided the best test

bench for the CAAP demonstration site for the following reasons:

- Texas provided the greatest commercial development potential for marine shrimp with several existing pilot farms and a commercial shrimp hatchery.
- Its warmer climate provided an economic edge over other possible shrimp growout demonstration sites.
- The Intercoastal Waterways System and several ports provided numerous opportunities to employ existing DMCAs.

The choice for a prospective CAAP demonstration site was further narrowed to the Brownsville Navigation District's Brownsville Ship Channel (BND and BSC). The BND and BSC were an ideal location for the test demonstration because of its proximity to an epicenter of the traditional Gulf of Mexico shrimp trawling industry and its processing, packaging, storage, and marketing infrastructure.

Demonstration Site Constructed Facilities

The facility is located adjacent to the BSC (Figure 1). The demonstration projects culture facilities (nursery and growout ponds were developed from one large dredge material containment pond that had been actively used for dredge material placement for the past twenty years or more). The culture facilities consist of a 4-acre (1.6-hectare (ha)) nursery pond and two growout ponds: Pond A (104 acres, 42 ha), and Pond B (about 116 acres, 47 ha). Modification of existing works at the site included:

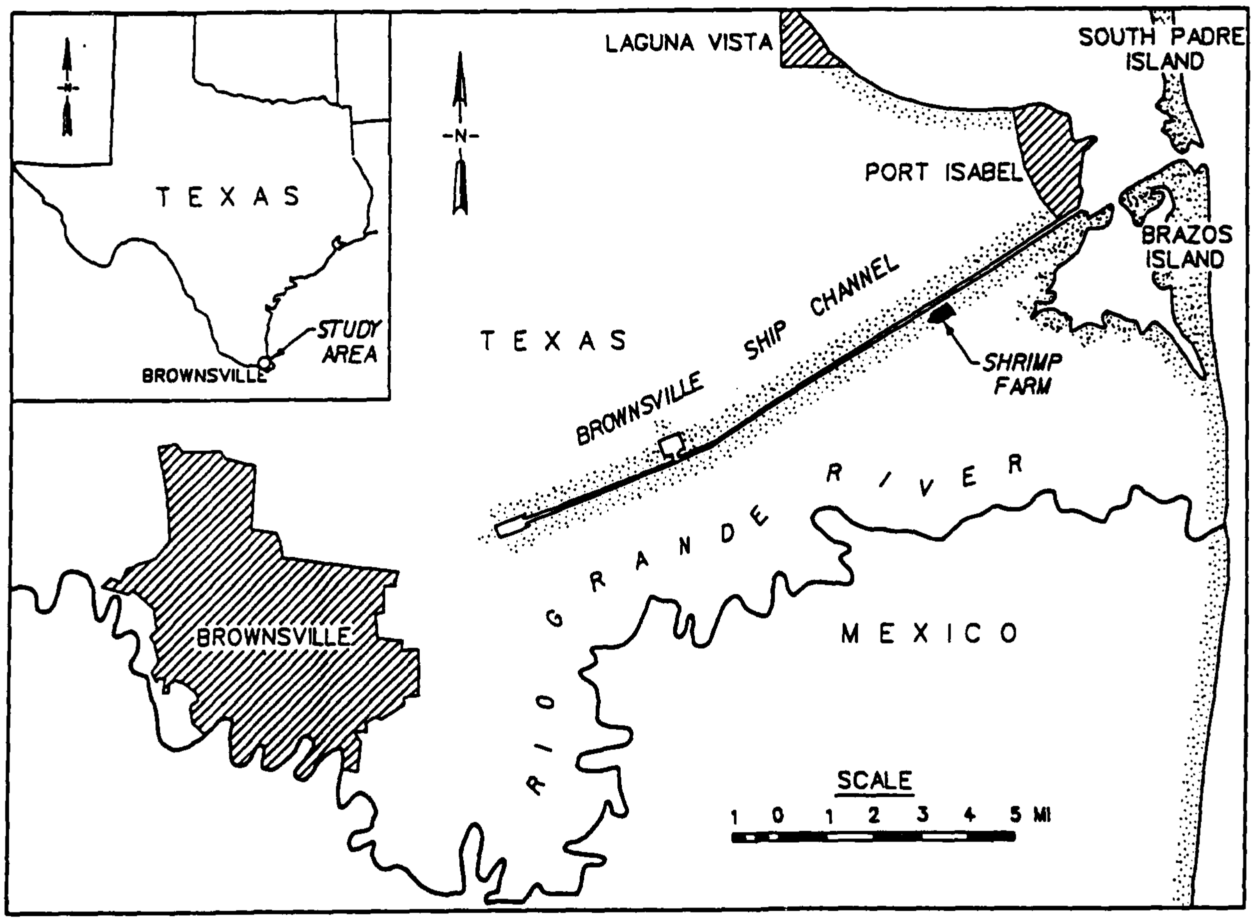

Figure 1. Location of the CAAP Shrimp Farm Demonstration Project

- Dividing the original dredge material containment pond in half, making two separate growout ponds.
- Raising and widening the perimeter levees to a minimum of 6 ft (1.8 m) above pond bottom with a crown width of 12 to 15 ft (3.7 to 4.6 m).
- Construction of a 2.5-acre (1-ha) raised operations area.
- Leveling and construction of interior drainage ways.
- Construction of a water intake canal and water distribution channels.
- Construction of an in-levee water-control/harvest structure.

Details of the main production components are shown in Figure 2.

Intake Water System

Water is pumped from the intake canal by two 10,000 gallon per minute (gpm) (38 cu m/min) and one 20,000 gpm (76 cu m/min) diesel pumps located in the pumping station. The pumps were set on a concrete slab and housed in a frame building because of the excessively dusty and corrosive environment. The building was made so that the only permanent openings were screened soffit vents under the edge of the roof, which opened and faced down. Cooling air for the diesel pumps (and diesel generators in a room adjacent to the diesel pump engines) that the building housed was sucked through the soffit vents and discharged to the outside of the building by the push type radiator cooling fans on the respective diesel engines. This hot radiator air was discharged through openings in the side of the building facing the ship channel (least dusty) side of the building. These radiator discharge openings

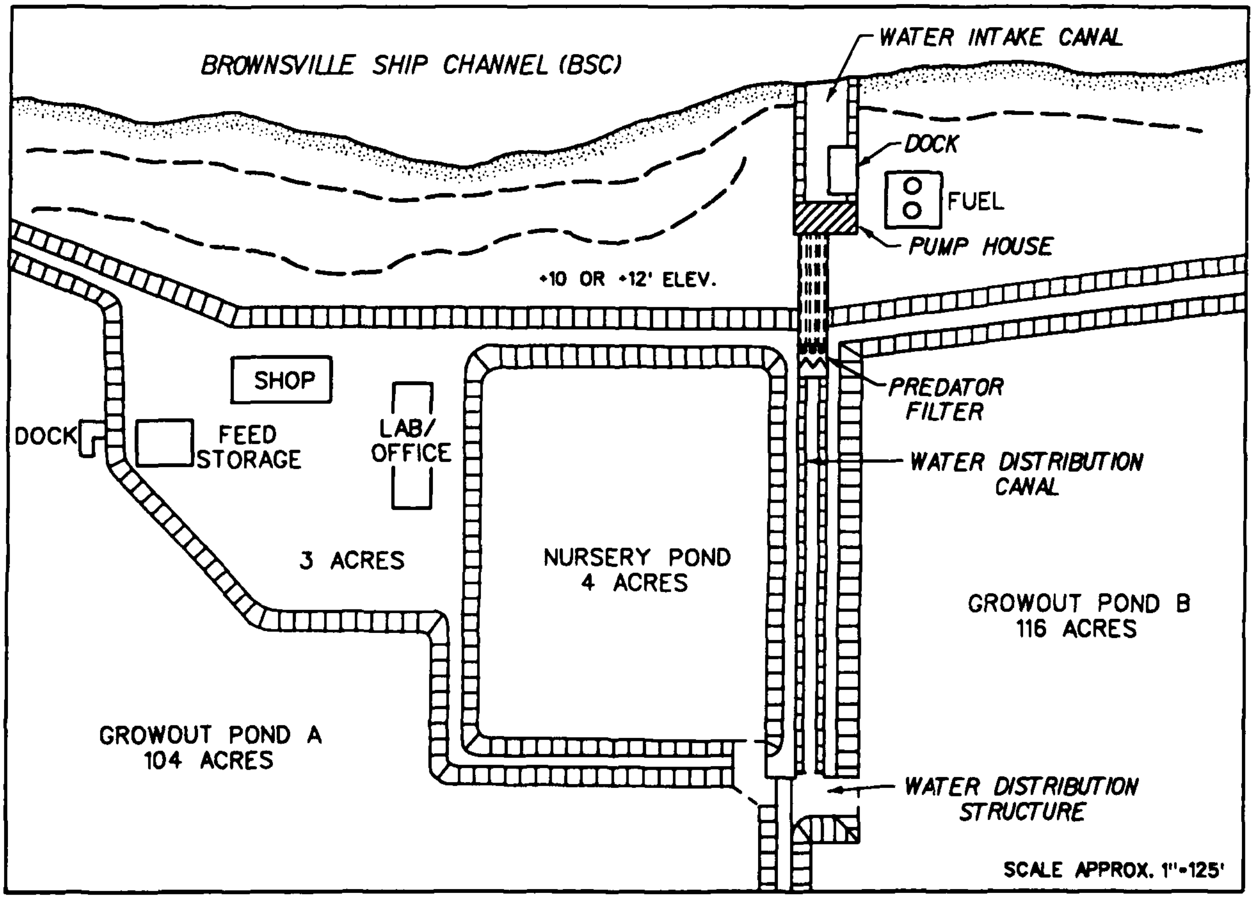

Figure 2. CAAP Shrimp Farm Demonstration Site Infrastructure Layout

were covered with normally closed louvered ventilators. When the engines started, the air pressure from the radiator fans forced open the louvers and discharged the hot air coming from the diesel radiators to the outside of the building. When the engines were off, the vents were sealed shut.

Other special design features to the pump and generator building included removable walls in front of and behind the diesel pump engines so that the engines and the pumps could be easily accessed for maintenance. The generator room had an overhead type garage door for access.

Predator Filter System

After being lifted to 12 ft of elevation, the incoming water then passes through a predator filter system (250-micron screen) into the water supply canal and distribution structure which supplies the nursery pond or the production ponds as needed. Since the BSC is the site of many species spawning, it was decided early on that a predator filter would have to be designed that could separate fish larvae and juveniles from the intake water and return them relatively unharmed downstream to the BSC.

To accomplish this filtering task, a filter system was designed, consisting of a series of fine meshed screens in side by side vee configuration. The screens were housed in a concrete block filter box. The screens were constructed of pressure treated lumber and were 6 ft high by 16 ft long. There were four sets or galleries of vee screens containing eight screen panels. The screen panels were designed so that they would slide in and out of grooves in the filter box. The filters were then sealed to the concrete walls and floor using a plastic foam edge on the filter frames and a rubber flap in the upstream face of the filter frames.

The vee configuration of the screens would cause the angle between the water flow and the opening of the screens to be almost perpendicular thereby creating a self-cleaning effect when solids collected on the surface of the screens. In other words, the solids would be swept across the face of the screen downstream to a collection point. This collection point was a four inch diameter vertical PVC pipe that had been slotted. The vertical slots of the PVC pipe were attached and located between the apex of the vee screens. In this way each of the four filter galleries had one manifold that could receive solid debris. Inside of this slotted manifold was another 4-in pipe which reduced slightly in diameter by slotting the pipe its entire length. This interior pipe acted as a valve for the manifold by rotating within the manifold, aligning the slot of the manifold and the interior pipe for discharging collected solids or rotating to the opening in the manifold until it was blinded by the interior pipe shutting off any discharge flow.

Water entered the front of the filter box in an open area that acted as a header box section. This header box section acted as a distribution manifold dividing the water evenly between the four filter galleries. It was found that water had to be introduced into the header box below the water level of the header box. This prevented aeration of the water which in turn prevented subsequent foaming and protein separation of the incoming seawater. When protein separation occurred, the proteins coated the normally self-cleaning polyester screens and caused debris to adhere to the screens causing them to foul.

Water level in the filter box was controlled by dam boards or stop logs. Normally the level of the filter box operated where the water covered about three fourths of the screens' surface. This allowed a safety margin in the event that the screens might foul and cause the filter box to overflow. An overflow channel was designed on the side of the filter box to prevent the filter box from overflowing into the adjacent shrimp ponds. The overflow gate and channel ran to the filter solids discharge canal which in turn flowed back to the BSC (Figure 3).

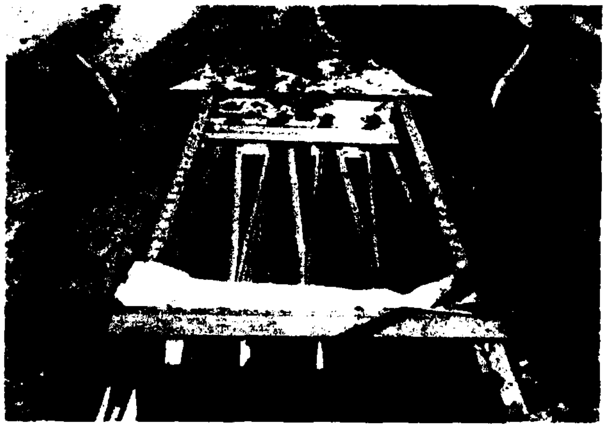

Figure 3. Predator filter

Water Distribution Structures and System

Nursery pond

Water for all the ponds was carried from the predator filter by a distribution channel. Water for the nursery ponds was supplied from the distribution channel by two 15-in. PVC pipes from the distribution channel through the channel/pond levee. The pipes flow was controlled by an elbow on the up-stream side of the pipe. The elbow could be rotated down allowing water to flow from the distribution channel into the nursery ponds. To prevent the shrimp from swimming up-stream through the pipe into the distribution channel, flapper valves were installed on the discharge/pond side ends of the two 15-in. PVC pipes. The nursery pond may also be filled by sending water from the distribution channel through the drainage monks thereby backfilling the nursery pond.

Growout ponds

The distribution channel carried water to and past the nursery pond to the growout ponds. A common structure was built to divert water from the distribution channel to either A or B growout ponds. The structure was also common the drain and harvest system of the nursery pond which allowed this structure to be multi-purposed and to be used to carry juveniles from the nursery to either growout pond or to rapidly backfill the nursery pond from the water distribution channel or from a growout pond (sometimes it was desirable to inoculate the nursery ponds with plankton blooms). The structure was constructed of concrete block (12 inches wide) and water flow was controlled by a series of dam board systems between each of the respective sources and discharge points.

Pond Drainage and Harvest Structures

Nursery pond

All pond water levels are determined by the height of the dam boards in the water-control/harvest structure in each pond. The nursery ponds have two monks for draining. However, because of their design and location, they are capable of the following multi-purpose functions:

- Draining the nursery pond.
- Filling the nursery pond from the distribution channel.
- Filling the nursery pond from the growout ponds.
- Transferring juveniles from the nursery to growout ponds A or B.
- Harvesting juveniles from the nursery pond to be transferred or collected by the harvest pump.

A concrete culvert 24 in. in diameter was installed vertically in front of the nursery pond monks' drain screens. The 3-ft-deep culvert/sump was recessed 8 in. into the concrete apron of the nursery pond. This sump allowed the levee stationed harvest pump to pump (without suction cavitation) all of the nursery pond's juvenile shrimp to be counted and transferred (Figures 4).

Growout pond

Both nursery and growout ponds were designed to allow their drainage in a 24-hr

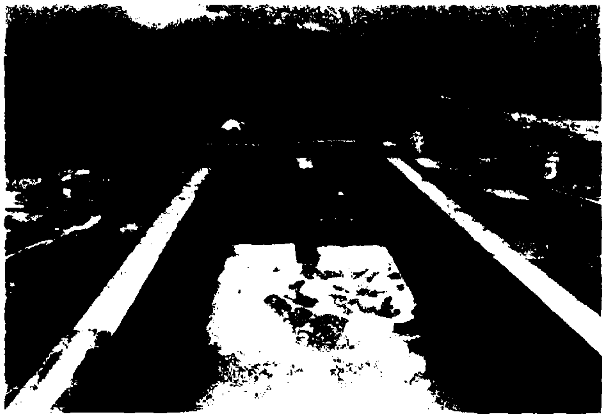

Figure 4. Nursery pond drain structure operating

period. Since no one had ever drain harvested growout ponds of this large size before, there was little data on which to base our harvest design. The drain and harvest system was based on scaled up designs of successful systems in smaller ponds.

To facilitate drainage and drain harvest, pond bottoms were channeled. These channels connected all of the surveyed low spots on the relauvely flat pond bottom into a central drainage channel. The channel system was a tree shaped pattern, where the base of the tree's trunk was the lowest point and the location of the drain harvest structure. The channels were vee shaped measuring 20 ft (6.09 m) wide at the top and averaging less than 2 ft (61 cm) deep through the drain structure. The drain harvest structure itself was designed to be simple, relatively inexpensive to construct (typical drain structures used for DMCA purposes are made of steel and cost about 20 percent more than the ones designed for aquaculture), durable, but specifically for rapid and effective shrimp harvest.

The drainage and harvest structures are constructed similarly to the water distribution structure and the nursery drainage structures in that they are made of 12-in.-wide concrete block with re-bar and poured cement centers and employ the same conceptual designs. To achieve rapid high volume low velocity drainage, the growout pond drainage structure consists of nine monks in a side by side configuration. The monks use treated wood dam boards which slide into slots on the monk walls. These slots are formed by bolting two treated 2 x 6 planks to the monk walls. Past experience has shown that this wooden slot system is easier to install and maintain than formed concrete slots in monks. The wooden slots—unlike the concrete formed slots—are adjustable to different dam board thicknesses and can be loosened in place should the dam boards swell in the water and jam in place.

A second set of wooden slots in the monks receive a set of vee shaped screens to exclude the shrimp from leaving with the water during drain downs and exchanges. A harvest basin or sump located outside the weir or monks in each harvest structure was designed to accommodate the cone end of the harvest net system, which is used only during harvest operations when the pond is drained completely (Figure 5).

On Site Support Facilities

On site support equipment and facilities for the commercial scale CAAP Shrimp Farm Demonstration included:

- A 24-ft speed boat (45 mph) and a 20-ft aluminum pontoon barge for staff and materials transport to and from the site.
- A club cap full size four wheel drive pick-up.
- Two Haul Master Utility Vehicles for efficient on site transportation around the three miles of pond levees and for feeding the nursery pond. These vehicles seem to be in constant use on the site and were like motorized tool boxes carrying up to six people and their tools and materials to the area where they were working.
- A boat landing in the intake channel in front of the pump station. Since access time to the site by boat was 10 to 20 min compared to 1 hr by car this proved to be very useful. Having docking facilities also proved useful to barge in fuel, supplies, materials and barge out harvested shrimp during extended periods of inclement

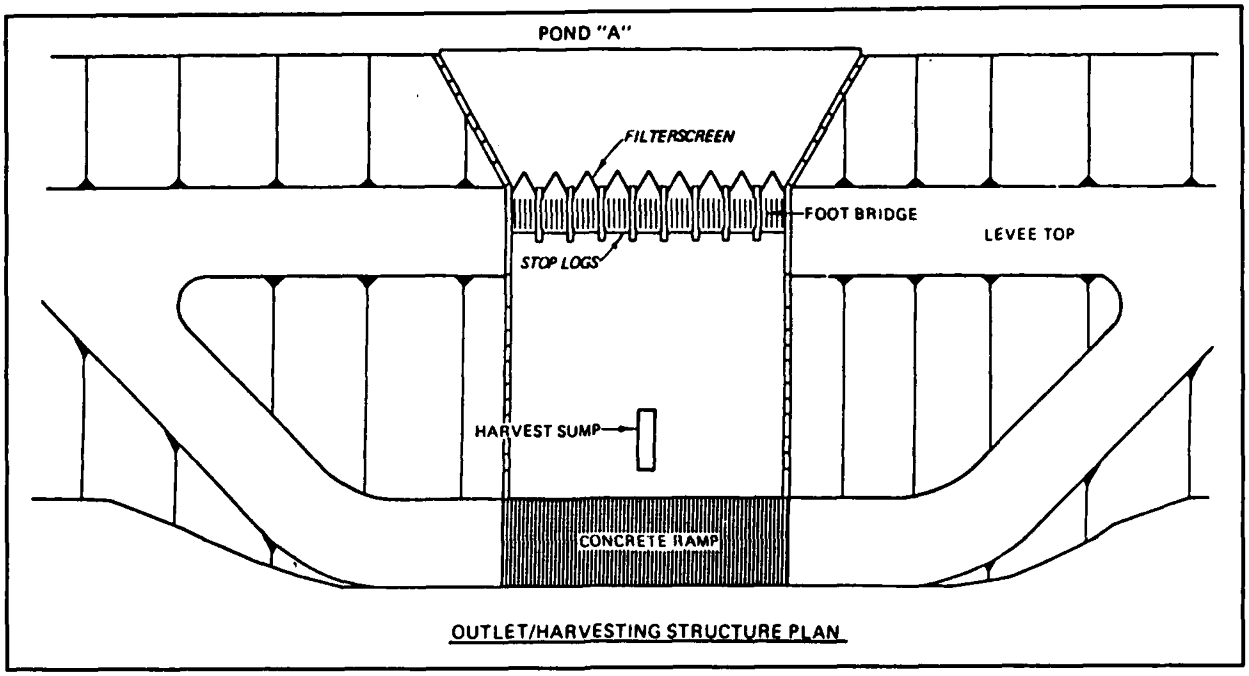

Figure 5. Design of drain harvest system

weather. Extended bad weather (rain) made the 7-mile-long dirt road from the CAAP Demonstration Site to the highway impassable.

- A John Deere agricultural heavy duty model diesel powered backhoe tractor with various accessory attachments (scrapper and forklift forks for the front-end loader).

- Two fiberglass (rust proof) fuel storage tanks. The site maintained 3,000 gal of diesel fuel for pumps and generators and 2,000 gal of gasoline for boats and vehicles.

- Two 20-kw diesel generators for domestic use and to aerate the nursery pond. The generators were located in a separate room in the pump house.

- A double wide mobile home used as a laboratory and doubled as the on site managers residence.

- A 6,000-sq-ft enclosed pole barn used for storage of tractor, truck, boats and as a maintenance shop.

- A portable building used for feed storage.

- Feed boat docks in each growout pond. The feed barge could be loaded with a ton of feed simply by rolling the feed bags on cart from the building to the end of the dock and pouring the feed directly into the feeder hopper.

- A desalination system for fresh water supply and 1,000-gal fiberglass storage tank system. Later site operators chose to replace desalination with a 1,000-gal polyethylene water transport tank/trailer because of less maintenance, greater efficiency and dependability.

- CB radios and a cellular phone that provided communications with the business office in town. The cellular phone proved to be the most useful, especially late at night when the office was closed and weather conditions limited or eliminated radio transmissions by CB.

Maintenance Program Design

All on site equipment was maintained according to manufacturer's specifications and schedules. Rust, corrosion, and dust were the greatest maintenance malefactors. Permanent protection to ferrous metal equipment was provided by regular sandblasting and painting with marine epoxy paint systems. Preventative corrosion maintenance was accomplished using copious quantities of WD-40.

Maintenance of the pond bottoms was accomplished between crops using the on site staff, contract labor, and the site backhoe. Pond levee maintenance became a problem because of the size and fetch of the wind on the pond surfaces. To prevent levee erosion on the windward side of the ponds, old hay bales (bound with synthetic twines) were purchased and stacked along the pond water line. Continued wave action cause the hay to sink into the levee beach. The hay bales soon became saturated with levee material and salt which made them heavy and more like large bricks. They were biologically degraded very slowly forming a detritus in the ponds that the shrimp were seen to eat especially at night.

Feeding System Design

The nursery pond required, by comparison, a small amount of feed. Consequently, the nursery pond was fed by broadcasting the feed by hand.

To feed large ponds efficiently and successfully, the feed must be broadcast over as much of the pond bottom as possible. To accomplish this, a gasoline powered feeder blower was designed and constructed. The feeder frame and hopper was made of wood and plywood respectively. A commercial duty leaf blower was used to provide an air stream with a velocity of 187 mph to entrain the shrimp feed pellets. The feeder was mounted on the deck of an aluminum pontoon barge/boat powered by a small outboard motor with a shielded propeller to prevent damage to shrimp (Figure 6).

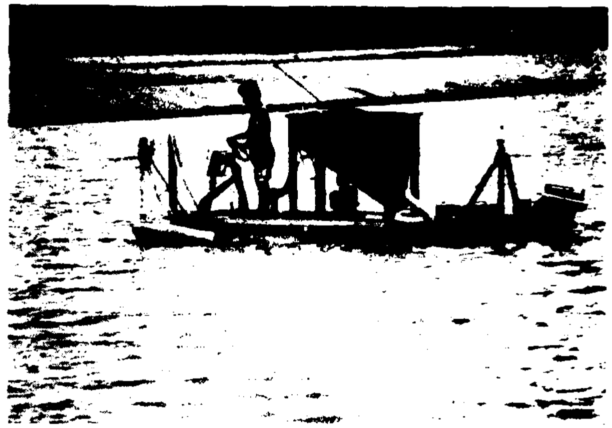

Figure 6. Feed barge with feed blower unit

To ensure even and consistent distribution of the feed over the growout pond, a series of numbered stake poles, with numbers visible, were set in the growout pond bottoms well above the water. By following the numbered stakes in sequence, a pattern was produced by the feed barge operator that allowed the feeder to evenly cover most of the pond area while the feeder broadcast the feed in a wide swath. When sampling of the shrimp revealed that one part of the pond was not being used by the shrimp the feeding stakes were moved to cover the areas of the pond that were being more utilized by the shrimp.

Production Strategy Design

The primary production strategy was to produce edible-sized shrimp, using a two-stage, semi-intensive growout system. In this system postlarval shrimp approximately 1 mm in size were purchased from a shrimp hatchery and stocked in a nursery pond where they were fed a 45-percent protein feed for 4 to 6 weeks.

Having the first stage of growth in a comparatively small nursery pond allowed:

- More rapid response to water quality needs due to the smaller and more easily mixed volume.

- Ability to mechanically aerate the nursery pond using electric powered paddle wheels powered from on site generators.
- Concentration of juvenile shrimp in a smaller area for more efficient feeding.
- Easier monitoring of health, collection of samples for growth rate analysis.
- More efficient and economical exclusion of waterborne predators.

After the juvenile shrimp reached a size of about 25 mm, they were transferred to a larger (100 plus acres, 40 plus ha) growout pond. Throughout each crop, the shrimp were sampled by castnet, and the data developed on growth and standing crop biomass was used to calculate feeding rates. Though growth estimates tended to have variability, the crops were consistently slightly larger than sampling estimates demonstrated. This helped feed conversions to remain consistently below 2:1. It should be noted that the shrimp congregated by size class and each size class tended to select certain parts of the pond. In general smaller sized shrimp seemed to prefer shallow water whereas larger shrimp preferred deeper water. This made sampling ponds over 100 acres in size a challenging task.

In five of the six attempted crops, shrimp were stocked in the growout ponds at a minimum of 40,000 per acre (10 shrimp per sq m). The shrimp were fed a pelleted commercial feed at a rate of about 3 percent of body weight per day for about 16 to 24 weeks. Growth was closely monitored and shrimp were harvested when overall growth leveled off, or production stocking schedules conflicted with the next planned crop. Pond water was exchanged as needed to reduce algae blooms from shrimp metabolites and to reduce high salinities (due to the areas high winds and temperatures). The intake pumping system for the demonstration farm operating at full capacity was capable of exchanging 10 percent of the total water volume each day.

One crop was attempted using an extensive (natural production) culture method. The economics of extensive production can be attractive when nature provides much of the food energy for the shrimp crop. Without the use of large quantities of high protein feeds, water quality is maintained with less pumping. Also, with less invested in an extensive crop of shrimp there is less risk during any type of catastrophic failure. Shrimp were stocked at a lower rate of about 8,000-20,000 per acre (2 to 5 shrimp per sq m) and were not fed any commercial feed, although the pond was periodically fertilized with purled urea and Super Phosphate to enhance the growth of naturally occurring food organisms. Results of this crop were not conclusive due to a failure in the initial predator filter system and the introduction of predatory fish into the growout pond.

While shrimp are also commercially produced using intensive culture methods, they were not used in the CAAP demonstration because of the extensive nature of typical DMCAs. In intensive culture, stocking rates may be as high as 200,000 to 400,000 per acre (50 to 100 shrimp per sq m). Intensive culture of aquaculture animal biomasses exceeding approximately 1,000 lb per acre (1,000 kilos per ha) may require continuous mechanical aeration and massive water exchanges of up to or exceeding 100 percent weekly to prevent catastrophic die offs from lethally low dissolved oxygen levels. This level of intensity was viewed as atypical for the resources offered by the generally remote location of DMCAs with regard to road access and large quantities of electrical power.

Harvest System Design

Shrimp ponds can be harvested by trawling, seining, or draining. All crops produced in the demonstration were harvested by draining. During harvest, dam boards and screens were gradually removed from the center sections of the drain/harvest structure. The shrimp moved out with the discharged water which passed through a framed trawl-like epoxy coated expanded metal mesh cage that had its cone shaped end down in a 3-ft-deep (1-m-deep) harvest sump (Figure 7).

Figure 7. Drain harvest system during harvest

The harvest machine (Figure 8), consisting of a fish pump mounted on a trailer attached to the end of the expanded metal mesh cone, pumped water and shrimp into an elevated dewatering tower located over the fish pump. The harvest machine was located beside the drainage and harvest gates with its other end abutted to the side of a loading platform (flatbed semi-trailer). On the other side of the loading platform, two semi-tractor trailer trucks were parked with their respective trailer end doors opening directly onto the loading platform. At the end of the loading platform, an ice crusher/blower machine was located. The ice crusher/blower machine was fed ice from a third semi-tractor trailer truck. Shrimp moved down a 6-in. (15.24-cm) pipe from the tower into 1000-lb (450-kg) capacity totes which were iced in layers (shrimp and ice alternately) while filling and then loaded onto the adjacent semi-tractor trailer truck.

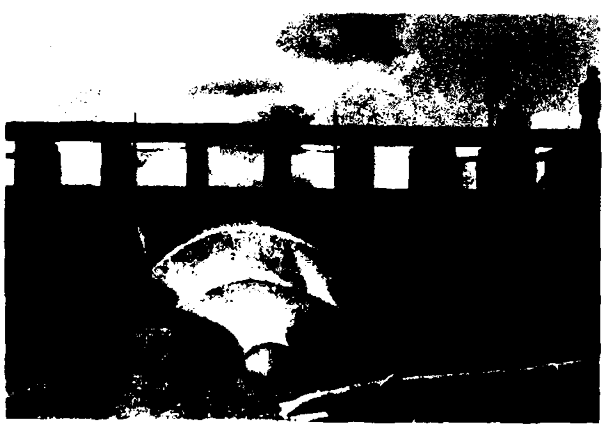

Figure 8. Harvest pump intake sump

When full, the semi-tractor trailer would shuttle the iced shrimp to a processing plant while the second truck remained behind being filled. Using this method, the relatively large ponds were harvested in as little as 33 hr from start to finish, resulting in a fresh, top quality, premium marine shrimp product.

Production Operation Brief

Six crops were attempted during the three-year operation of the demonstration facility. Of these, two crops did not produce commercially attractive yields, one due to cold temperatures in winter 1989 and the other due to predation by fish introduced when the predator screen fouled in summer 1988. Four successful crops were harvested. Production rates for the four crops averaged 597 lbs/ac (669 kilograms per hectare (kg/ha)) of whole shrimp (range: 334 to 1,143 kg/ha) with 51 percent survival (range: 23 to 74 percent). Total production of 256,329 lbs (116,269 kg) of whole shrimp (156,001 lbs or 70,761 kg tails) was sold for over $475,000 which was deposited in the U.S. Treasury (Figure 9).

Figure 9. Shrimp havest sample

Demonstration Facility Disposition

At the conclusion of the demonstration project, the shrimp farm facility was transferred to the BND, an independent political entity of the State of Texas and the local dredging sponsor. The BND received over 25 inquiries regarding leasing from private investors and leased it to a private shrimp farming enterprise in mid-1990's.

Information Transfer Documents

Information obtained by the CAAP will also be published in six technical reports. Topics include site selection and acquisition, legal and regulatory requirements for DMCA aquaculture, chemical suitability of DMCA for aquaculture, economic and marketing analysis of the demonstration, engineering design and construction, and description of project operations and production methods. In addition, a CAAP guidance manual for use by USACE field offices will be produced.

A third group of publications covering the same topics as above will be produced by the National Sea-Grant Program and will be oriented toward prospective aquaculturists, investors, and financial institutions. These extension publications will be available at Sea-Grant offices throughout the nation by late 1992.

Future Prospects for DMCA Aquaculture

In the demonstration facility, the South American white shrimp *Penaeus vannamei* was the main species produced. This species is used by most of the commercial aquaculturists in the western hemisphere. It tolerates crowding, is relatively hardy, has a good growth rate and is available as postlarvae from commercial hatcheries. However, it is a tropical species that requires temperatures above 22 °C for acceptable growth. In the semi-tropical climate of South Texas it has a 7-8 month growing season. In more temperate climates, a more cold-tolerant species such as *P. chinensis*, *P. penicillatus*, and *P. japonicus* will be required. Short sighted environmental regulations against the use of these exotic species now prevent the use of the previously listed species in the State of Texas.

Although the CAAP demonstration project was a penaeid mariculture enterprise, aquaculture designs in DMCAs are by no means limited to shrimp or even to marine species. There are over 250,000 acres of aquaculture facilities for channel catfish and freshwater crayfish in the Southeastern United States, and these industries are profitable and expanding. In areas where DMCAs may be located near temperate freshwater, there is a potential for containment area aquaculture of these species.

In cold water areas, commercial aquaculture facilities for rainbow trout and salmon are expanding in many countries, including the United States. Various species of salmonids can be produced in either freshwater or saltwater. Under current production practices these are usually grown in raceways or cages rather than ponds; therefore, salmonid have less potential for DMCA aquaculture than warm water species. However, production practices for these salmonoid are evolving, and pond culture remains a possibility.

Another commercial aquaculture enterprise that has potential for use in DMCAs is shellfish culture, including mussels, oysters, and hard clams. These shellfish are produced in coastal facilities in the United States and tolerate cold water temperatures. Another species with potential is striped bass. The culture for striped bass and striped x white bass hybrids is being researched in several states. These fish have rapid growth rates and good marketability. In states where hybrid stripped bass culture is legal and commercially feasible, they would make excellent species for aquaculture in DMCAs.

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CAAP Demonstration Farm Production Operations

by
Mark Konikoff[1]

Introduction

Six crops were attempted during the three-year operation of the demonstration facility. Of these, two crops failed: one due to cold temperatures in winter 1989, and one due to predation by fish introduced when the predator screen fouled in summer 1988. Four successful crops were harvested. Production rates for the four crops (Figure 1) averaged 597 lbs/ac (669 kilograms per hectare (kg/ha)) of whole shrimp (range: 337 to 1,143 kg/ha) with 51 percent survival (range: 23 to 74 percent). Total production of 256,329 lbs (116,269 kg) of whole shrimp (156,001 lbs or 70,761 kg tails) was sold for over $475,000, which was deposited in the U.S. Treasury.

Production Techniques and Strategies

The primary production technique was to produce edible-sized shrimp using a two-stage, semi-intensive growout system. In this system, postlarval shrimp, approximately 1 mm in size, were purchased from a shrimp hatchery and stocked in a relatively small nursery pond where they were fed a 45-percent protein feed

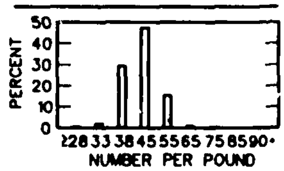
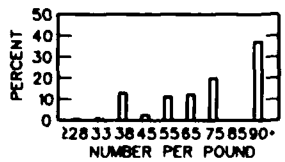
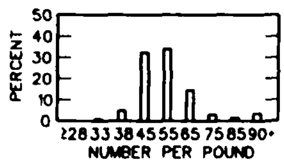
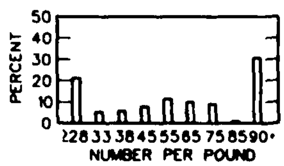
DATE	POND	kg/ha (lbs/ac)		SURVIVAL	TAIL SIZES
SUMMER 87	A	1143	(1020)	74%	
FALL 87	A	522	(465)	56%	
SUMMER 88	B	676	(603)	51%	
SUMMER 89	A	337	(301)	23%	
	AVERAGE	669	(597)	51%	

Figure 1. CAAP production of P. vannamei in ponds

[1] University of Southwestern Louisiana, Lafayette, LA.

for 4 to 6 weeks. Having the first stage of growth in the small nursery pond allowed close monitoring of water quality, juvenile shrimp feeding, health, and growth rate. In addition, water exchange, mechanical aeration, and the exclusion of predators are more manageable in a small pond. After the juvenile shrimp reached a size of about 25 mm, they were transferred to a larger grow-out pond.

In the semi-intensive crops, shrimp were stocked at a rate of 40,000 per acre (10 shrimp/sq m) of grow-out pond. The shrimp were fed a pelleted commercial feed at a rate of about 3 percent of body weight per day for about 16 to 24 weeks. Growth was closely monitored and shrimp were harvested when overall growth leveled off or operations conflicted with the next planned crop. Pond water was exchanged as needed to reduce high salinities. The system was capable of exchanging 10 percent of the water volume each day.

One crop was attempted using an extensive culture method. Shrimp were stocked at a lower rate of about 8,000-20,000 per acre (2 to 5 shrimp/sq m) and were not fed any commercial feed, although the pond was periodically fertilized to enhance the growth of naturally occurring food organisms.

Shrimp may also be produced using intensive culture methods (not used in demonstration). In intensive culture, stocking rates may be as high as 200,000 to 400,000 per acre (50 to 100 shrimp/sq m). Intensive culture requires continuous mechanical aeration and massive water exchanges of 100 percent weekly or more. In some cases, water in intensive systems may be filtered or otherwise purified and then reused.

Shrimp ponds can be harvested by trawling, seining, or draining. All crops produced in the demonstration were harvested by draining. To facilitate drain harvest, pond bottoms were contoured to allow for efficient draining through the drain structure. The structure itself was designed specifically for effective shrimp harvest.

Dam boards and screens were gradually removed from the center sections of the drain/harvest structure. The shrimp moved out with the discharged water which passed through a framed trawl-like net that had the cod end in a harvest sump. A fish pump attached to the cod end pumped water and shrimp into an elevated dewatering tower. Shrimp moved down a pipe from the tower into 1000-lb (450-kg) capacity totes which were iced in layers (shrimp and ice alternately) while filling and then loaded onto an adjacent trailer truck for hauling to a processing plant. Using this method, the relatively large ponds were harvested in as little as 33 hr from start to finish, resulting in a fresh, top quality, premium product.

Production Results

1987 harvests

Only Pond A was used for production operations in 1987. Two crops of the white shrimp, *Penaeus vannamei* (cycles: March to September and July to December), were harvested. Yields attained in the first crop were 106,038 lbs (48,098 kg) of heads-on shrimp (1,020 lbs/ac or 1,143 kg/ha) and in the second crop 48,425 lbs (21,965 kg) equaling 465 lbs/ac (522 kg/ha). Reduced production in the second crop was attributed to early cold weather in October, reducing growth and survival. While Pond A was in production during spring and early summer 1987, the adjacent Pond B was used for dredged material placement.

1988 harvests

In 1988, a semi-intensive crop of 70,460 lbs (31,960 kg) of heads-on shrimp equaling 603 lbs/ac (676 kg/ha) was produced in Pond B. Production, survival, growth, and feed conversion efficiencies were not as good as those for the previous summer. The causes of this reduced performance were not clear, but prolonged high salinities (130 days above 36 parts per thousand) and possible poor quality of postlarval seed stock were suspected. No adverse affects from the dredged material were evident.

The 2-year, per-crop average production from semi-intensive (stocking about 40,000 juvenile shrimp/ac or 10/sq m) shrimp culture exceeded 74,957 lbs (34,000 kg) which totals over 695 lbs/ac (over 780 kg/ha) at favorable feed conversion ratios and with good survival (averaging 61 percent). This was within the target production range for the demonstration.

Two alternative production scenarios were attempted without success. In the first alternative, an extensive (unfed) crop in Pond A was lost due to contamination by predator fish which entered the growout pond when the predator filter became clogged and then overflowed. About 1,500 lbs (700 kg) of 1 lb (0.5 kg) *Cynoscion nebulosus* (spotted sea trout) were present at harvest, and shrimp survival was only 3.4 percent. An electronic system to warn staff of potential overflow situations was developed and installed to prevent reoccurrence.

The second alternative was an attempt to grow a winter crop using a reportedly cool water tolerant species, *P. penicillatus* during the winter of 1988-89. These shrimp were killed by unusually low temperatures during February 1989.

1989 harvests

A semi-intensive crop in 1989 suffered from an international shortage of seed stock which prevented timely stocking. Postlarvae were stocked in small amounts as they became available over several months. These undesirable circumstances resulted in poor survival and growth with final production only 31,206 lbs (14,155 kg) of heads-on shrimp equaling 301 lbs/ac (337 kg/ha) with over 60 percent being small (over 50 tails/lb). Figure 1 summarizes overall production for the three crop years.

Development of CAAP Economics Computer Model

by
David Marschall[1]

Abstract

Once the demonstration project was established and produced real-world data, specific start-up costs and crop returns were identified and quantified. These demonstration results were then used in formulating a computer model that allows a user to test the economic feasibility of raising various animals in Dredged Material Containment Areas (DMCAs) of different sizes.

The primary objective of the DMCA model is to provide a spreadsheet template with the features necessary to input specific data, perform what-if scenarios and obtain calculated results which will enable the user to make sound economic and marketing decisions which must be considered prior to starting an aquaculture business.

Specific requirements of the model were to:

- *Be useful to both Corps of Engineers (CE) district personnel and the landowners who are not experts at either dredging or aquaculture.*
- *Be flexible to analyze selected variables that may be peculiar to certain species in different parts of the country.*
- *Allow separation of expenditures of the aquaculturist and the CE district.*
- *Be personal computer (PC) compatible, portable, and designed for the novice PC user to operate with a minimum amount of computer knowledge.*

After reviewing several existing aquaculture economics models, a special model for DMCA aquaculture was developed and tested with live data to identify specific start-up investments, variable and fixed costs, and potential crop returns over a specified period of time. The final analysis of the computer model provides the aquaculturist with differences in annual expenses, net income/loss, and cash balance figures with and without financial assistance from the CE district.

The DMCA model is a combination of six worksheets developed with Lotus 1-2-3, a software spreadsheet product of the Lotus Corporation. The worksheets accept and calculate data for:

- *Construction Costs.*
- *Initial Investment Costs.*

1 C-K Associates, Inc., Baton Rouge, Louisiana.

- *Annual Variable Costs.*
- *Annual Fixed Costs.*
- *Annual Sales Summary.*
- *Annual Income Statement and Annual Cash Balance Statement.*

The spreadsheet format will accept initial input, perform required calculations, and update figures from page 1 to page 6. Once the worksheets are filled in, individual or multiple parameters can be changed and the results of these changes can be viewed immediately. This is a significant advantage of the spreadsheet format. However, the six worksheets are designed so that they can be used without the computer performing all of the calculations.

The worksheets require the user to input a number of cost figures. These figures may have to be estimates, as in the length of a pond levee, or they may require some research into typical values either from aquaculture literature or experts. Examples of these are the cost of fingerlings or the number of pounds of a species that may be harvested per acre.

Although the worksheets require considerable input, they are structured to assist the potential aquaculturist in initiating a thorough pre-project evaluation. Standard financial analysis concepts are incorporated to prompt the user to consider the full range of factors and to appreciate their relationships.

The computer model was used to test the feasibility of rearing either crawfish, catfish, hybrid striped bass, or clams in a DMCA. The results of these tests can be reviewed in literature available from the U.S. Army Engineer Waterways Experiment Station in Vicksburg, MS.

CAAP Economic Analysis[1]

by
Kenneth J. Roberts[2]

Abstract

Although the demonstration project was a commercial-scale operation, it was not designed as a commercial operation would be. Existing aquaculture technology for smaller ponds was adapted to the demonstration site where existing containment areas of over 100 acres each already existed. Despite this origin, the project met the purposes for which it was established and generated much new information to give perspective for future aquaculture in Dredged Material Containment Areas (DMCAs).

The project did reveal a significant value to the lowered start-up or entry costs. Containment area levee cost estimates by the Galveston District were $1,600 and $900 per acre for Pond A and Pond B, respectively. When compared to aquaculture literature, these values appear closer to the per acre value for smaller ponds. The demonstration project ponds were 100+ acres each, but were compared to cost data from the literature for smaller ponds near 20 acres each. Engineering, surveying, design, and permitting work, if performed by the Corps of Engineers (CE), could be worth $400 per acre. For the demonstration project, the combined capital savings was estimated to be $271,000. The annual drain on cash flow of the estimated $271,000 start-up capital needs would have been $63,000.

In an industry known for scarcity of funds available from financial institutions, this capital savings is both real and valuable. Investors characteristically provide a high share of an aquaculture project's start-up capital because most projects lack full institutional support. Not only could the lowered immediate demand on cash outflow increase chances for company success, but a DMCA aquaculture venture would be available to a wider number of prospective companies. This is an outlook which will be of value not just to large containment areas like those at the demonstration project, but to smaller sites suited to more intensive operations or part-time operators.

The value to a new aquaculture facility's investor(s) of DMCA use is up to now unquantified. Whatever quantification there could be will produce site-specific numbers. The CE and aquaculture companies have similar needs for accessible sites, perimeter levees, containment areas (ponds) of various sizes, water-retaining

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[1] This presentation was based on information from the following publications: *Economic potential of aquaculture in dredged material containment areas* by Kenneth J. Roberts, David G. Marschall, and Jurij Homziak. Mississippi-Alabama Sea Grant Consortium; March 1992, Publication No. MASGP-90-32.

[2] Louisiana State University, Baton Rouge, LA.

soil, and water control in impoundments. When these needs can be met on a site that is technically conducive to aquaculture, an economic opportunity exists.

The major potential investment-reducing incentive to use a DMCA is the pond construction cost. Wet soils of coastal areas and the remoteness of sites could make DMCA projects more costly because levee material may have to be hauled. The large pond size of the demonstration project made construction costs lower on a per-acre basis. Use of a pond construction value to prospective culturists of $800 per acre for DMCA culture appears to be a reasonable point for reference.

There is also value to reducing investment capital needs for engineering, design, surveying and permitting. To the extent that the CE, or ports and waterway districts provide these services, an additional value of $400 per acre could occur. Using estimates of investment needs from the aquaculture literature, a combined value for pond engineering, design surveying, permitting, and construction of $1,200 per acre can be justified.

For the approximately 230-acre CAAP demonstration project, this amounts to $271,000. The reduction of investment capital needs may be as important to increasing lender support as it is to lowering break-even costs since capital availability is a well known constraint in the aquaculture industry.

Sales and Marketing

by
Les Hodgeson[1]

Introduction

Prior to WWII, the United States produced fresh shrimp from a fleet of small vessels that fished close to shore during daylight hours only and caught solely white shrimp. Brown shrimp were present but unknown because they disappeared into the mud during daylight hours at depths never touched by our shrimp boats of those days. Imports, except some canned shrimp, were negligible, and our local production of fresh shrimp was packed in barrels for express rail shipment to inland markets or canned locally for retail shelf sales. There were no freezers at point of production.

The end of WWII signalled an explosion in the industry created by a number of factors all happening almost simultaneously. First of all, the returning servicemen had been exposed to seafood items such as shrimp and scallops and wanted more. The post-war boom created an increase in chain-store outlets and white table cloth restaurants. On the supply side, events could not have been more prosperous. Oil drilling in the Gulf disclosed gigantic beds of brown shrimp that required night fishing and larger boats to handle the drags at lower depths. Local shipyards were readily available to give our domestic shrimp fleet an expanded field of endeavor. The double rigging of vessels to allow drags from both sides increased the catches. Wartime plants, originally constructed to freeze fruits and vegetables, were converted into shrimp packing and freezing facilities, and refrigerated trucks were available to allow national distribution of a frozen product. The introduction of breaded shrimp and its immediate popularity in a market that then accentuated deep-fat frying was a lifesaver for an industry that was fast becoming top heavy on the supply side.

Shrimp Market

All of the foregoing developed over a very short period of time and created a market phenomenon. Unlike most products, as supply increased, prices did not decline—they advanced. True, there were several glitches, but generally the graph of supply in pounds and the line of price per pound show practically straight line increases.

I have not expounded on some of the other important facets that affected the industry over the years, the most significant being the imports of shrimp from all over the world, totalling over 500 million lb in 1990. Added to our domestic production of 1990, over 350 million lb, those current market sales figures I showed you for New York, are truly indicative of the popularity and demand for shrimp in our country today. It is continuously and unarguably the number one seafood item in all states based on current reliable surveys.

Shrimp has many qualities that promote market growth and sales appeal. It is not fattening; it is easily and quickly prepared; it is an excellent salad item; and is both an appetizer and an entree. It lends itself to many forms of presentation: sauces; breadings; batters; etc. It is extremely popular with children, lending itself to colorful advertising and pictorials. Frozen, properly packed and handled, it has a long shelf life. Unlike many other products, freezing does not in any way damage its taste or adversely affect its quality. Shrimp can be boiled, broiled, baked, deep-fat fried, stir fried, microwaved, grilled, or bar-b-qued. It is constantly on restaurant menus and is rapidly becoming a leading item in fast food establishments. Shrimp is frequently being featured in the rotogravure and recipe sections of the

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[1] Marco Sales, Inc., Brownsville, TX.

newspapers and food magazines and is easily the most popular item on cocktail party buffets. It is a product that is the constant envy of the food business.

The Farmed Shrimp Sales and Marketing

Now we have the possibility of a farm raised food product of national popularity and the technical ability to raise it to maturity on land of little use in other applications. Production problems exist, but they are solvable, and not the subject of this presentation. We have established that the market exists; that it is national, dynamic, and constant. But, where do pond owners fit in? How do they get in, and just how is market value established?

First of all, it must be understood that the United States shrimp market is completely free of government restrictions such as import duties, quotas, tariffs, etc. There are no crop subsidies, and the only government involvement is the FDA Regulations and Customs labeling restrictions. The correct "Country of Origin" declaration is closely monitored.

The head and intestines constitute approximately 35 percent by weight of the whole shrimp. The alimentary canal (called the vein) runs from the head through the body (called tail) and ends under a segmented fantail. The headless section therefore consists of the body section which is scaled, sectioned, and shelled; the alimentary canal (vein) legs; swimerettes' and a fantail. It is this product which is called Headless Shrimp, which can be sold fresh or frozen, and are graded for size to establish "count per pound," which is used to establish market prices and statistics.

You, as the seller, and certainly any potential buyer, must have some reasonable estimate of what your pond will produce when harvested. To provide this information, it is necessary to resort to a series of tests and computations. There are probably several methods which can be employed, but one in use now will be used here to provide an example. Using cast nets, the pond is sampled at various points in order to procure a cross section of the current crop by size and weight. For our purposes, this sample could consist of 1,000 whole head-on shrimp, sorted into the standard counts, then each count weighed. Using the percentages this produces for the various costs and making an assumption of a total pond harvest (based on the size of the pond), one can compute the weight in pounds of the various costs of head-on shrimp likely to be produced. Standard conversion tables can then be used to convert these figures to a headless shrimp basis when needed. Of course, this will be by no means completely accurate but has been found a satisfactory method to provide both buyer and seller with the advance information necessary to make bids and to evaluate comparisons between competitive bids and against current markets elsewhere.

This information can be disseminated to your list of potential customers together with your terms of sale. Generally, sales are made in one of two forms:

- Head-on, pond-side with all expenses assumed by the buyer including ice, transportation, etc.
- Headless tail weights with the buyer paying all processing charges, including ice and transportation.

It is also important to note that the pond owner can reserve the right to refuse all bids and can then have the shrimp processed for his own account.

The problem of how to intelligently evaluate the bids now presents itself and requires certain vital information. Basic to the matter of price per pound of the various counts for head-on shrimp, there is as yet no published set of prices that can be quoted. The entire subject of price is based worldwide on headless counts per pound, and this, therefore, requires that both buyer and seller must have headless counts and weights in mind when making comparisons. If the buyer elects to buy head-on, he has to presume that the sampling is reasonably accurate or that his price

is low enough to allow him leeway. The pond owner however has to use his sampling figures on a headless basis in order to convert the buyer's offer and compare it to the headless market or other bids received for headless shrimp on the same crop. It is to be recognized that once the buyer of head-on has loaded the crop and paid for it, the deal, for better or worse, is completed, and there is no recourse.

A far safer alternative is offered by Option 2, to sell on a headless basis. In this event we are dealing with a number of assets that are significant. First, in order to arrive at tail weights, the product, at buyers expense, must be transported, properly iced, to an established processing operation which is usually run by the same party that will do the grading. This must be performed in order to arrive at the headless weights per count on which the sale was made. These operations should be normally performed by reputable, experienced operators of local freezers that can be relied upon to treat both buyer and seller fairly. This method also gives both parties an opportunity to monitor the results and gives the pond owner an accurate assessment of his sampling accuracy.

Most important of all, however, is the fact that accurate comparisons can be made, not only between individual bidders, but also a comparison with the current market elsewhere. It is an important consideration, also, that as a safety measure, the pond owner can refuse all bids and process his crop for his own account, paying the expenses himself.

Additionally, the pond owner can publish his request for bids several days in advance of harvest date so that he will have ample time to contact potential buyers and evaluate their bids with due caution, or consider processing for his own account. With his request for bids properly worded, there would be no problem in canceling the harvest completely and rescheduling later, providing growth factors and weather conditions are favorable.

Current prices and market conditions can be obtained from several sources:

- Ex-vessel headless shrimp prices paid to boat owners in the major ports on the Gulf are hardly a secret and properly evaluated can be of great value.
- Local processors and/or freezers can be questioned and their authenticity established over short periods.
- Several very important and thorough market newsletters, together with National Marine Fisheries Service statistics which cover all markets on all species, are available.

It must be appreciated that the reliability of any of these sources is always suspect for many reasons not necessarily connected with their integrity. It can be stated that a seller availing himself of all sources, plus the bids themselves, will be in a position to make an intelligent decision.

Now we arrive at the final and most important ingredient in marketing your product, your customers. That they exist cannot be denied. You can be sure that many of them have been watching the development, of your ponds from day one, and it is highly likely that you have been visited and romanced long before you could take off a crop. Due to a strong demand for shrimp, there is equally a strong competition between buyers. Even when the overall demand may slow, it still remains a seller's market, and you can be confident you will get spirited bidding. It is essential, however, to accumulate a comprehensive list of desirable customers for contact by phone, fax, or mail when ponds are going to be offered. The actual solicitation can be made and evaluated by the pond owner, or through a sales organization composed of pond owners or a trade organization that handles other matters as well. Regardless of the means employed, the owner retains the final right of acceptance or rejection.

If it is decided to reject all bids and pursue the course of processing into frozen for the owner's account, there are certain factors to be considered. The standard worldwide package of frozen headless shrimp is a 5-lb unit. Of course the product has been graded and each resultant count will be packed into 5-lb boxes, frozen, glazed, and packed for storage into master cases containing 10 x 5s or 50-lb nets. Each individual carton requires proper labelling, and such cartons showing no brand can be supplied by commercial freezers. It is recommended, however, that the owner, or his organization, has his own branded cartons in order to establish an identity in the marketplace. Such a package, properly graded, frozen, and glazed is in demand on a daily basis. Second, this method of packing allows the owner to withhold sale until satisfactory conditions can be met.

In conclusion, I would like to stress the fact that those contemplating a venture into shrimp mariculture are favored with a product whose national reputation for quality and universal popularity has been established and maintained by the vessel owners. Any adverse publicity of any kind to the word shrimp, and all it stands for can be serious to all segments of the industry. Furthermore, in the matter of price, there is certainly a mutual interest to maintain the highest possible prices for the product. This should be of prime concern in providing selling-price information, by any means that can be employed, among all concerned.

Catfish, Tilapia, Redfish, Hybrid Striped Bass, and Baitfish as Candidate Species for the Containment Area Aquaculture Program

by
Robert R. Stickney[1]

Introduction

Aquaculture, the rearing of aquatic organisms under controlled or semi-controlled conditions, involves production of such plants as seaweeds as well as both invertebrate and vertebrate animals. In this paper the emphasis is on a selected group of finfish species. The list is not exhaustive by any means, but it does contain species of proven or potential aquaculture importance in the United States and is geared toward species which can be readily reared in ponds.

Aquaculture has a long history in the United States with respect to the production of fish for enhancement stocking by state and federal government hatcheries. Commercial aquaculture did not come into its own until the 1960s. Research during that decade and the two that followed was largely aimed at improving production efficiency and the performance of the species under culture. In recent years, increasing concern about the encroachment of at least some aquaculture enterprises on wetlands, use of the commons for commercial fish and shellfish production, and in some cases perceived and sometimes real environmental impacts from aquaculture enterprises have increasingly constrained aquaculture development. The current permitting environment makes development of aquaculture facilities extremely difficult in riparian and coastal regions.

At the same time that aquaculturists are looking for suitable sites, the necessity of maintaining the various waterways in the United States through maintenance dredging has led to some loss of wetlands for disposal of dredged material. Various options exist, including: offshore disposal; creation of new wetlands as mitigation for losses to dredge material disposal areas; and the transformation of dredge material disposal areas into productive environments. One type of productive environment, which would also provide economic benefit, is the establishment of confinement area aquaculture ponds.

Various scientific and social-political reasons mitigate against the use of many dredge material disposal areas for containment aquaculture, but given the dimensions of the current situation with respect to dredging, it should easily be possible to find a considerable amount of area in which containment aquaculture can be accommodated.

Reduced to its basic components, aquaculture has only a few major needs. These include a reliable source of acceptable quality water, some type of compatible species or group of species to place in that water, and a container into which the water and culture species can be placed and retained. These requirements are discussed below in the following order: culture chambers; water source and quality; and species for culture. Generalizations about culture chambers and water source and quality can be applied to each of the species selected for inclusion in this discussion. Many of the details that apply to the culture of channel catfish also hold for the other species under consideration. Therefore, more detail is provided relative to channel catfish culture, and the other species are discussed in terms of their respective individual requirements

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insofar as those requirements are somewhat unique.

Culture Chambers

There are three basic types of culture chambers employed by fish culturists: ponds; raceways; and cages. Fish culture ponds are typically rectangular earthen structures ranging in size from 0.1 ha to perhaps 10 ha in size. While larger ponds have been constructed, management of them for fish culture tends to be difficult, so smaller units of from 0.25 to 5 ha predominate at many facilities. Ponds feature levees with slopes of 1:2 or 1:3 (for every meter of elevation the base of the levee is 2 or 3 m wide). Pond bottoms typically slope at about 1 percent toward the drain. When the standard fish culture pond is filled with water, depth normally averages 1 m with a maximum depth of about 2 m.

The levees and bottom of each pond should contain a minimum of about 25-percent clay to retard leakage, though a variety of commercial liners can be obtained that will prevent seepage losses. Pond liners, while often effective, can add appreciably to the cost of pond construction.

Ponds should be fitted with drains so the entire water volume can be eliminated during harvest and pond maintenance as desired. Drain lines should be large enough to allow each pond to be completely drained within a few days. Similarly, inflow water should be available in sufficient quantity to fill each pond within a few days and should be continuously available in the quantity required to replace seepage and evaporation losses as necessary. In some instances water is flushed through ponds to ameliorate water quality problems.

Uncontaminated dredge material, depending upon its composition, may be suitable for the construction of aquaculture ponds. Ponds can be constructed entirely below the original ground level, partially above and partially below the original ground level, or entirely aboveground. Dredge material containment sites are created by building levees not dissimilar from those of aquaculture ponds. A large containment area might need to be divided into several ponds to keep the surface area per pond manageable. The levees of the containment area could be designed to hold the requisite dredge material while leaving the needed amount of water capacity for fish culture following disposal.

Raceways may be linear or circular. Linear raceways tend to be a few meters wide and tens of meters long. Circular raceways (tanks and silos) range in diameter from less than a meter to 10 m or more. In raceway culture, water continuously flows through the culture chambers and is discharged with or without treatment and recirculation. Turnover rates vary from minutes to hours and depend on the species being cultured, stocking density, and water availability. While earthen raceways could be constructed from dredge material or from concrete, fiberglass, metal, or some other material and placed on land constructed of dredge material, raceway culture would not seem to lend itself particularly well to dredge material containment sites.

Cages are typically constructed of nylon netting or one of a variety of plastic mesh materials placed around a frame equipped with floatation. The dimensions of fish culture cages vary widely with many being one or a few cubic meters in capacity. Larger cages, called net-pens, are used in the marine environment where tidal flows can be used to maintain water circulation and where deep water is present.

Cage culture could easily find a place in containment aquaculture. Instead of constructing several small ponds out of dredge material, cages could be placed in a large containment reservoir. Access to cages can be by boat or from a fixed or floating dock that links the cages with the shore.

Water Source and Quality

Water supplies used by fish culturists include municipal sources, wells, runoff, and

water pumped from surface sources such as rivers, lakes, reservoirs, and coastal embayments. While any of those sources could conceivably be used in conjunction with a containment aquaculture site, the most likely sources would be from wells or an adjacent surface water source.

Regardless of its source, the water should be of suitable quality to support the fish species being cultured. Temperature is a primary consideration. While water temperature may not be within the optimum range for the fish year round, it should be of the proper temperature to promote rapid growth for several months a year. In most instances, it is desirable to market fish produced under aquaculture conditions no later than the second year of life and preferably more rapidly (some species of particularly high value may be cultured for longer periods).

A second important water quality variable is dissolved oxygen. For most fishes, dissolved oxygen should be maintained at about 5 mg/l, though some species can tolerate somewhat lower levels. The situation in water sources that are deficient in oxygen can be corrected by the simple expedient of spraying the water through the air, allowing it to flow over splashboards, or by aerating with blowers, air compressors, or even bottled gas or liquid oxygen.

Culture water should generally have pH in the range of 6.5 to 9.0, with alkaline pH being particularly important for marine and estuarine fishes. Hardness and alkalinity should be 20 mg/l or higher. Freshwater species can often tolerate some salinity, and euryhaline species have, by definition, a wide salt tolerance. None of the species discussed here are obligate marine animals, and all can readily tolerate freshwater.

The water used for aquaculture should be free from pollutants which may directly affect performance and survival or which could accumulate in the flesh and become detrimental to consumers. One of the precepts of aquaculture is that the water in which fish are reared needs to be of the highest quality possible. When water quality begins to deteriorate, the fish will become stressed and may develop increased susceptibility to a variety of diseases.

Species for Culture

Channel catfish

The channel catfish, *Ictalurus punctatus*, would seem to be an ideal candidate for containment aquaculture sites in freshwater and brackish areas. The fish are predominantly found in freshwater rivers in nature, but they have been shown to tolerate up to approximately one-third strength seawater. Culture of them in brackish water would require a source of freshwater to replace evaporative losses in order to prevent constantly increasing salinity during the growing season.

Current production technology could be immediately adapted to containment sites, with the most likely option being the use of ponds of 5 ha or less, though channel catfish can also be readily produced in cages. Fingerlings could be produced by the containment aquaculturist or purchased from a dealer. The following paragraphs provide a synopsis of how catfish are currently being produced in the United States.

Channel catfish spawn in the spring, beginning when the water temperature reaches about 21 °C. Broodfish, generally no larger than about 5 kg, are maintained in their own ponds during most of the year and may be stocked into spawning ponds in the early spring.

In most instances more females are stocked than males because an individual male will mate with more than one female during the season. If released into an open pond, the fish will be allowed to select their own mates. Alternatively, pairs of spawning adults can be stocked in pens constructed within the spawning pond. This technique is particularly useful to fish farmers who are interested in attempting to improve their stocks through selective breeding.

Spawning containers are provided for use by the fish whether they are spawned in open ponds or in pens. The containers can be made of nearly any non-toxic material. Milk cans, grease cans, nail kegs, drain tiles, and home-made wooden boxes are among the types of spawning containers that have been employed. The basic requirement is that the container needs to be large enough to accommodate the pair of broodfish and should allow them to turn around.

Catfish

The male catfish will clean out the spawning container prior to mating. Natural spawning usually occurs, but females in spawning pens are sometimes induced to spawn through hormone injections. Females deposit several thousand adhesive eggs which will form a gelatinous mass on the floor of the spawning container. Once spawning has been completed and the eggs have been fertilized, the male will eject the female from the container and will supervise egg incubation by fanning the egg mass with his fins.

In most cases the catfish farmer will remove the eggs for incubation in a hatchery. Spawning containers should be checked two to three times weekly for the presence of eggs which can be easily scraped from the spawning container. Large egg masses may be broken into two or more pieces for incubation. While a variety of incubators have been successfully used, the standard method continues to be placement of egg masses into hardware cloth baskets that are submerged in small raceways (hatching troughs) equipped with slowly rotating paddle wheels that simulate the fin fanning action of the male catfish. Well aerated water is provided on a flow-through basis, along with supplemental aeration in most hatcheries.

After a week or so, depending on water temperature, the eggs hatch, and the fry fall through the hardware cloth to the bottom of the hatching troughs. Fry are usually allowed to remain in the hatching troughs until they begin feeding, which requires about an additional week. The fry will absorb their yolk sacs over several days and then rise to the surface of the water seeking food. Finely ground trout feed is generally provided. After the fish are firmly established on prepared feed, they are stocked into nursery ponds at rates of up to a few hundred thousand per hectare.

Nursery ponds are prepared prior to stocking by encouraging a plankton bloom. This is accomplished by providing inorganic fertilizer at 10-day to 2-wk intervals for several applications until the water is green and visibility is about 30 cm. The plankton bloom shades out rooted aquatic plants that might otherwise develop and provides natural food for the young catfish.

The young catfish may be retained in the initially stocked nursery ponds throughout their first growing season, or they may be stocked into growout ponds at reduced density one or more times during their first year of life and may even be introduced into growout ponds at a few weeks or months of age. Stocking density, water quality, and feeding regime are important in controlling the size of the fish at the end of the first growing season. Typically, the fish will be from 10 to 20 cm long going into their first winter. If optimum temperature conditions can be maintained indefinitely, it is possible to produce a 0.5-kg marketable fish in 8-10 months, but most farmers do not have optimum conditions for that length of time and depend upon two growing seasons to produce marketable animals.

When the catfish farming industry was developing, most ponds were harvested during the fall after the water temperature had cooled to the point that little or no growth was occurring. That practice placed most of the annual production in the processing plants, and subsequently into retail outlets over a very limited period of time. In the past several years, intermittent harvesting has been widely practiced. Rather than draining and harvesting each pond annually, ponds are now selectively harvested with seine nets that capture marketable fish while having sufficiently large mesh to allow undersized animals to escape. A pond might be seined once a month or so at which

times the marketable fish are removed. New fingerlings might be added from one to several times a year to replace harvested fish, and the pond will continuously have a variety of sizes present. This technique works well with catfish because they are not cannibalistic so various sizes can be grown together effectively.

Ponds that are intermittently harvested can be kept in production for a few years after which accumulated organic matter can lead to reduced water quality and the presence of increasing numbers of stunted fish can lead to reduced fish productivity. At this time the pond should be drained and completely harvested. The harvested pond should be dried out, and the bottom aerated by disking. Levee repair can also be affected, after which the pond may be refilled and stocked once again.

Production in well managed ponds tends to average about 3,000 kg/ha. Higher production levels can be achieved if there is some exchange of water, particularly during the portion of the year when the water is warmest. Many Mississippi farmers have reported 4,000-kg/ha production levels and even higher in some cases.

Catfish farmers routinely monitor dissolved oxygen, particularly during the late summer when fish densities and metabolic rates are high and the demand on oxygen approaches its maximum. Dissolved oxygen problems typically occur during the early morning so farmers may have crews routinely measuring dissolved oxygen through the night or at least during the predawn hours. Automatic oxygen monitoring systems, that can dial an emergency telephone number and alert the farming of an impending oxygen depletion, are now available.

Many years of research have gone into the determination of the nutritional requirements of channel catfish, and some standard dietary recommendations are available and widely in use. Feed, which represents some 45 percent of the variable costs associated with catfish rearing, typically contains about four major ingredients: fish meal or meat and bone meal; soybean meal; corn, cottonseed, or peanut meal; and wheat. Supplemental vitamins and minerals are also provided to ensure that the feed meets the requirements for those nutrients.

As the fish grow in size, the particle size of the feed is increased until pellets of about 6 mm in diameter are provided. Feed pellets can be manufactured so that they either float on the water surface or sink. The manufacture of floating pellets is the most expensive of the two processes, but when floating pellets are used, the farmer has the added advantage of being able to observe the fish feeding. Not only can the farmer ascertain something about the health of the fish, but it is also possible to determine how much to feed. The fish are typically provided with the amount that they will consume in about 20 to 30 minutes. Catfish typically eat about 3 percent of their body weight daily during the time of year when the water temperature is in the optimum range of about 26 to 30 °C.

Catfish, like other fish species, are subject to a variety of diseases. These include: viruses; bacterial and fungal infections; and an array of parasitic problems. Sound management practices, including the avoidance of stress, will go a long way toward avoiding epizootic diseases, but even the most careful fish farmer will sometimes experience a problem. Vaccines are available for certain catfish diseases and can provide at least partial immunity. Other diseases must be treated with drugs and chemicals. The number of chemotherapeutics available to the culturists of catfish and other aquatic species is unusually sparse. Various drugs and chemicals which have not been cleared for use on fish being reared for human consumption are available. While government clearance could possibly be obtained for some of those substances, the costs to date have been prohibitive except in a few cases, leaving the fish culturist with a very small arsenal with which to fight disease outbreaks.

In the major catfish growing regions of the United States, such as the Mississippi Delta region, there are large processing plants where producers can sell their product. In some regions, catfish farmers sell fish in the round,

process the fish themselves, or sell their fish to another farmer who has a small processing plant.

Off-flavors, often imparting an earthy-musty flavor and odor, have been a major problem for the catfish industry. The problem is usually attributable to blooms of bluegreen algae in the culture ponds. Consumers who are exposed to off-flavor may never purchase another catfish. In order to avoid the problem, processing plants in Mississippi will not accept fish from a pond which has not been sampled three times. Each sample involves selecting a fish at random, cooking the tail portion in a microwave oven, and having a trained person smell and taste the cooked flesh. These tests are conducted two weeks before a pond is harvested, three days before harvest, and at the time the fish are delivered by truck to the processing plant. If a pond fails any of the three tests, it is quarantined until the algae bloom crashes and the fish metabolize the chemical that is responsible for the off-flavor. Fish can also be placed in algae-free water for several days while the off-flavor-producing chemical is eliminated.

The techniques described for channel catfish culture could easily be incorporated into a containment aquaculture facility that has an adequate source of low salinity water. Proximity to a processing plant and markets should be considered in the prospectus for such an operation. In some cases it might be most desirable to have on-site processing. Another innovation that may work, depending on location, would be the establishment of a fee fishing operation in conjunction with a containment catfish farming site.

Tilapia

Native to North Africa and the Middle East, tilapia of various species have been introduced throughout much of the tropical world over the past few decades. Various species are present in the United States. Few species can tolerate temperatures below 10 °C, but the fish have been successfully reared in geothermal waters year round and for much of the year in subtropical and temperate areas. Tilapia have been known to overwinter in south Florida and south Texas during most years, but exceptionally cold winters can lead to widespread fish losses in those states.

The taxonomy of tilapia has been quite confused in recent years. Most of the species of culture interest have been variously placed in the genera *Tilapia*, *Sarotherodon*, or *Oreochromis*, and there have been frequent proposed changes in the taxonomy. For example, the blue tilapia has been known as *T. aurea*, *S. aureus*, and *O. aureus*, all within the past 15 years. The American Fisheries Society Committee on Common and Scientific Names of Fishes, unconvinced by the rationale behind the proposed name changes, continues to recognize the genus *Tilapia* for all species being cultured in the United States.

Resembling sunfish, tilapia are extremely hardy, grow rapidly, are highly disease resistant (except when exposed to low temperatures), and have firm white flesh that is very well received by consumers. Aside from the overwintering problem, which necessitates rearing the fish to market size within a single growing season or overwintering fingerlings in heated water for stocking during the second growing season, the strategies for culturing tilapia and catfish are quite similar.

A considerable amount of research has been done to determine the nutritional requirements of tilapia. While specialized feeds can be manufactured or ponds can be organically fertilized to provide natural food for tilapia, it is generally cost effective to feed them catfish feeds.

Tilapia spawn virtually year round in the tropics, with females producing a new brood at approximately 30-day intervals. In temperate environments tilapia will begin to spawn in the late spring, and spawning will continue until the water temperature cools in the fall. Once a female is from 3 to 6 months of age, depending upon species, she will begin producing eggs. Males construct depressions, called nests, in the substrate, attract a female to the nest, and fertilize the eggs as they are

deposited. The female then picks the eggs up in her mouth, in the case of most of the commercially important species, and swims away, allowing the male to court another female.

The eggs incubate in the mouth of the female over a period of about one week, after which the fry remain in the female's mouth for another several days during yolk sac absorption. Once released from the mouth of the female, the fry will school around the female for an additional few days and seek refuge in her mouth if danger threatens. By the time the fry move off on their own, the female is about ready to spawn again. As a consequence of mouthbrooding, females don't have an opportunity to eat during much of the year and become stunted. In addition, the continued addition of fry to culture ponds through reproduction can lead to overstocking and general stunting of the fish.

Various techniques have been developed to eliminate spawning females or reduce spawning success in tilapia growout ponds. Handsexing to remove females when the fish reach about 6 or 7 cm has been used in some instances, but is time-consuming, expensive, and far from being completely effective. Tilapia have been reared in cages on the assumption that the eggs will fall through the bottom of the cage during spawning and be lost, thereby allowing the females to continue eating and growing. Predators can be stocked to consume fry as they are produced, but that will not affect the stunting of adult females. A highly effective technique involves feeding male hormone to first-feeding fry for a period of three weeks. Virtually all the fish treated in that manner become males through a process known as sex-reversal.

Tilapia tend to be fairly tolerant of saltwater, and some species and hybrids are able to withstand full strength seawater or even water of higher salinity. Their ability to withstand salt could make tilapia a desirable alternative culture species in coastal containment situations.

Off-flavors have been reported from imported tilapia, but are considered to be extremely rare in fish reared in the United States. The fish have a high recognition level among Asians and are becoming increasingly well known within the United States population at large. Demand would undoubtedly increase if fish brokers could be assured of a constant supply of fish of premium quality.

Tilapia are usually marketed beginning at 300-400 g. Larger sizes are desirable for filleting, which will probably be the form desired by most American consumers.

Finally, since tilapia are exotic to the United States, there are restrictions associated with their culture in some states. Local permitting requirements should be investigated by anyone interested in rearing tilapia or any other fish species for that matter.

Redfish

Redfish (also known as red drum, channel bass, and spottail bass), *Sciaenops ocellatus*, can be found along the southeastern Atlantic coast and in the coastal waters of the Gulf of Mexico. There was not much interest in their culture prior to the commercial fishing ban imposed by the Texas legislature in 1981. The popularity of blackened redfish also prompted interest in the species, so for the past several years, a considerable amount of research effort has been expended on developing culture strategies. Researchers in Texas had developed the spawning technology needed to produce numbers of juvenile redfish before the ban was imposed. That technology was adopted by biologists with the Texas Parks and Wildlife Department with financial support of the Gulf Coast Conservation Commission which funded a large facility in Texas to produce fingerlings for enhancement stocking.

Juvenile and adult redfish are euryhaline, and the fish can be grown in freshwater as long as that water is relatively hard. The fish are sensitive to cold and survive cold weather better in brackish than in freshwater, though massive kills of natural populations in the Gulf of Mexico have occurred during unusually cold winters. Winterkill could pose a significant

threat to the aquaculturist and is a factor that should not be ignored when a culture species is being selected.

Broodstock, which normally spawn during fall, can be induced to spawn repeatedly by exposing them to the proper sequence of temperature and photoperiod changes, with the ultimate temperature and photoperiod being the same as those on the spawning grounds. Since females produce millions of eggs that are released at intervals of a few days, broodfish numbers can be kept low.

Fertilized eggs hatch after about two days, and the resulting fry can be stocked into ponds that have been fertilized to produce large zooplankton populations. Survival in properly prepared ponds ranges widely, but is often 25 percent or more between the time fry are stocked and fingerlings of 40 mm are harvested a few weeks later.

Redfish will consume pelleted feeds and can be reared on diets formulated for the production of trout. Some catfish formulations have also been effectively used to grow redfish.

Opinions as to the future of redfish farming vary widely. Once touted as an ideal culture species because of the demand for blackened redfish, competition from blackened catfish, which is considered to be as acceptable a product, may detract from the potential for redfish as a major aquaculture crop, because producing redfish cost more than rearing catfish. Research and development are needed with regard to redfish, but it should be a species that is adaptable to containment aquaculture sites, particularly in regions where it is native.

Hybrid striped bass

With the decline in native striped bass along the eastern seaboard of the United States, interest in commercial aquaculture of striped bass and hybrid striped bass has developed. Hybrid striped bass, most commonly produced by crossing striped bass (*Morone saxatilis*) with white bass, (*M. americana*), are preferred as they grow more rapidly than striped bass during their first 2 years, are hardy, survive well under culture conditions, and are apparently more disease resistant.

The basic culture strategy with hybrid striped bass is similar to that for redfish, with the primary exception that adult striped bass are taken from nature each year at the beginning of the spring spawning season. There is work currently underway to produce broodstock from captively spawned and reared striped bass, but the industry will undoubtedly have to rely on wild broodstock for a number of years. Obtaining permits to capture and spawn wild striped bass may be a problem in some states because of restrictions on the taking of those fish, though there should be no insurmountable legal problems associated with obtaining white bass brooders.

Hybrid striped bass eggs are usually incubated in hatchery jars, and the resulting fry are reared to fingerling size in tanks, raceways, or ponds. Fry can be introduced into ponds in which zooplankton blooms have been established in advance by fertilization with organic materials, such as grasses and oilseed meals, or with inorganic fertilizers. When reared in tanks or raceways, brine shrimp nauplii and other natural foods should be provided when the fish begin eating about 4 days after hatching.

Finely ground salmon starter feed is often introduced once the fish have begun actively feeding on natural foods. Conversion from natural to prepared diets is an important step in the process of culturing striped bass and hybrid striped bass. Providing natural foods to fish in tanks and raceways is time-consuming, expensive, and efficient only during the early stages of culture. In ponds, the fish will eventually exhaust the supply of zooplankton and will quickly learn to accept prepared feed.

After a month or two, fingerlings can be harvested from the fry rearing facilities and transferred into growout ponds. They can also be reared in cages. Salmon and trout feeds appear to meet the nutritional requirements of striped bass and hybrid striped bass. Little work has been done on the nutritional

requirements of these fishes to date, but as the industry grows, specialty feeds for them may be developed.

Striped bass hybrids can be grown in brackish or in freshwater. The fish are tolerant of elevated salinity once the juvenile stage is reached, but the early phases of culture should be conducted in freshwater.

Baitfish

While a large number of fishes have been cultured as bait, three are of primary commercial importance in the United States. They are the goldfish, *Carassius auratus*, golden shiner, *Notemigonus crysoleucas*, and fathead minnow, *Pimephales promelas*. There has been some production of killifish, *Fundulus* spp.), and that fish could be considered for culture in containment ponds located in estuarine areas. The selection of which species to grow should be influenced by local demand.

Spawning of each of the three major minnow species begins when the water temperature exceeds 20 °C. Techniques for spawning include intensive culture where the fry are separated from the adults and extensive culture where the offspring are allowed to remain in the ponds where the spawning adults have been stocked. For the extensive form of culture, adult fathead minnows and golden shiners are stocked at rates of no more than 5,000 fish/ha, while 35,000 to 60,000 fathead minnows/ha or 400 to 500 kg/ha of golden shiners are stocked for intensive culture. Extensive culture of goldfish involves stocking 250 to 750 fish/ha, while 800 to 1000 kg/ha of goldfish are stocked for intensive culture.

Fathead minnows spawn on the underside of vegetation and other objects, so appropriate spawning substrates should be provided. Goldfish and golden shiners will also spawn on plants, and the shallow areas of drained ponds can be planted with grass and later flooded to provide spawning substrate. Mats approximately 30 cm x 60 cm constructed by placing Spanish moss between pieces of welded wire can also be used as spawning substrates. These are particularly useful with respect to intensive culture as the eggs can easily be moved from the spawning pond to a rearing pond on the mats.

Ponds for production of minnows and goldfish should be fertilized with liquid fertilizer to induce a phytoplankton bloom that provides a visibility of about 20 cm. Once the fish reach 2.5 cm, the plankton bloom can be allowed to decline. When the fish are observed near the water surface, prepared feed should be provided. Powdered feeds are normally used, often in conjunction with organic fertilization to encourage the development of zooplankton. Commercial feeds are available for baitfish.

Goldfish and minnows are susceptible to a variety of diseases. Since they are not foodfish, the number of chemicals and drugs available for use on them is larger than for the other species described in this paper. A major problem can occur if predators such as various species of fish, birds, frogs, snakes, turtles, insects, and alligators are present in culture ponds. Control of some predators is difficult, and that difficulty can be compounded in cases where the predator is protected by law (e.g. alligators and many species of fish-eating birds).

Opportunities and Constraints for the Production of Red Swamp Crawfish, Freshwater Prawn, and Brine Shrimp in Containment Areas in the United States

by
William C. Trimble[1]

Introduction

Use of dredge material containment areas (DMCAs) for aquaculture has general benefits including: (1) increased availability of aquaculture sites near waterways and (2) reduced fixed costs for levees and water control structures (Coleman et al. in press). The objective of this report is to briefly describe the aquaculture of the red swamp crawfish (*Procambarus clarkii*), freshwater prawn (*Macrobrachium rosenbergii*), and brine shrimp (*Artemia franciscana*) and then relate opportunities and constraints of growing these species specifically in DMCAs within the United States.

Crawfish

The red swamp crawfish (*P. clarkii*) is the principal crawfish grown at aquaculture sites in the United States. The red swamp crawfish is indigenous to the United States, and the crawfish's current range includes 25 states (Huner and Barr 1991). As shown in Figure 1,

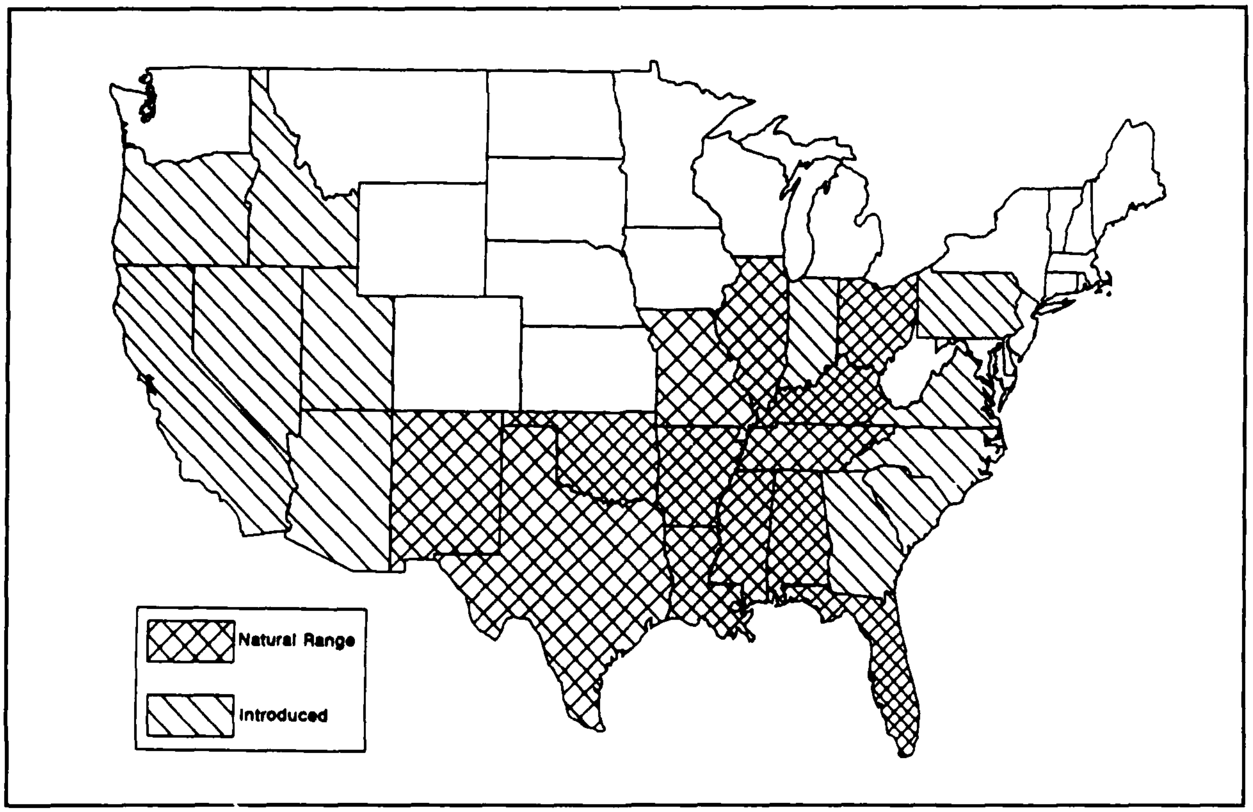

Figure 1. Distribution of the red swamp crawfish

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the range of the red swamp crawfish originally included the Mississippi River Valley and adjacent areas. Introductions expanded the range from the east to west coasts of the United States.

Aquaculture of the red swamp crawfish evolved during 60 years of commercial and research effort primarily in Louisiana. The crawfish is reared in earthen ponds, and techniques for optimal production are described in recent publications (de la Bretonne and Romaire 1989, Avault and Brunson 1990, and Huner and Barr 1991). About 90 percent of the crawfish acreage in the United States is in Louisiana (approximately 125,000 acres), and the red swamp crawfish is grown in nine additional states (Alabama, Arkansas, Florida, Georgia, Maryland, Mississippi, North Carolina, South Carolina, and Texas).

Production of the crawfish in earthen ponds is fairly simple. In late spring, female crawfish with eggs are stocked into new, shallow ponds which are slowly drained allowing the females to burrow. During the summer, aquatic plants are cultivated in the pond bottom. When the pond is refilled in the fall, juvenile and brood crawfish leave the burrow and graze on the vegetation. Most of the harvest occurs during the spring, and productions of 600 to 1,200 lb of crawfish/acre are obtained with traps baited with fish and/or artificial baits and often run with mechanized boats. Pond yields diminish in early summer as the crawfish burrow and market prices decline. After the first year of production, ponds usually are not restocked for the consecutive years of production.

Although many types of ponds produce crawfish (Craft 1980, Huner and Barr 1991), a rectangular, recirculating pond has the unique potential to circulate, conserve, and economize water (Baker 1987, as cited by de la Bretonne and Romaire 1989). As shown in Figure 2, the embankment pond contains baffle levees, return canal, and circulation pump in addition to the customary supply pump and an aeration screen to oxygenate influent.

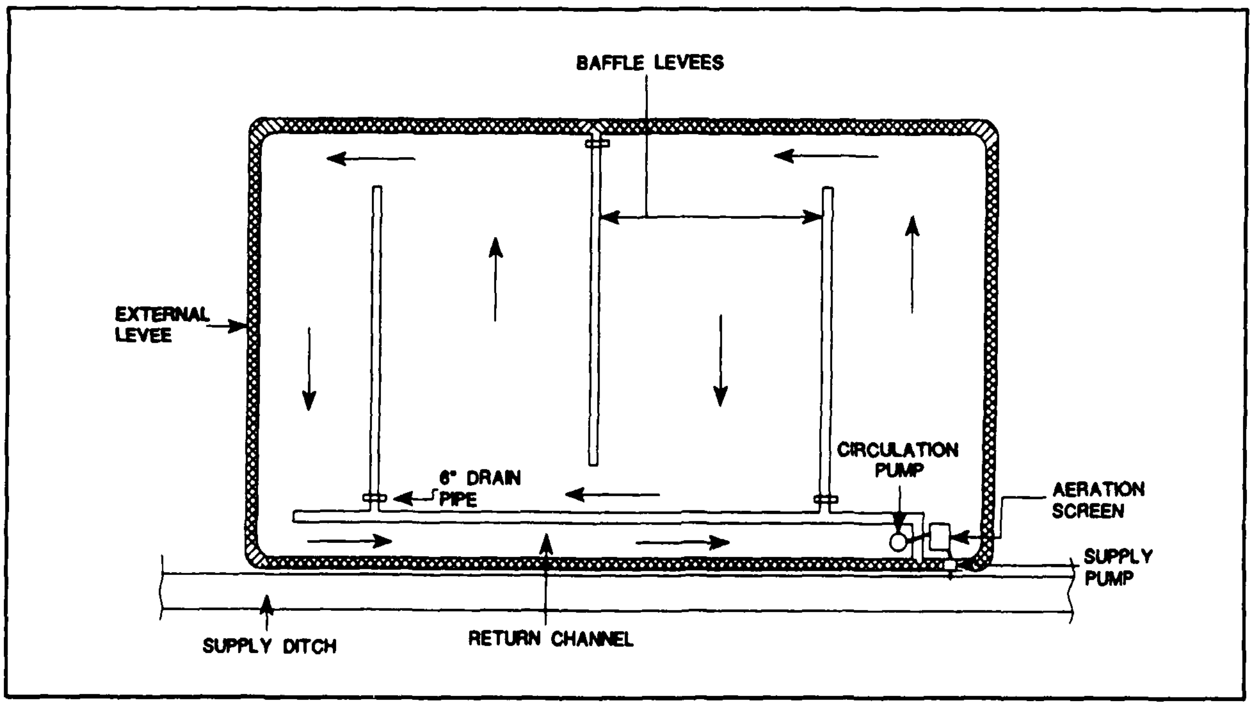

Figure 2. Embankment pond

Constraints for production of red swamp crawfish in DMCAs

Possible constraints to production of red swamp crawfish in DMCAs involve: levee height; pond size; dredged sediment; stocking schedule; water quality; and economics.

- **Levee height**. Maximum height for crawfish ponds is about four feet allowing a one-foot freeboard and a three-foot depth at the pond's deep end. The four-foot height facilitates entry of mechanized crawfish harvesters, rice combines, and tractors for establishing and maintaining aquatic vegetation. The low levees also promote additional revenues from duck hunting and trapping. On the other hand, very high levees on DMCAs might be used as reservoirs at sites with droughts or intermittent waterway flows. Water stored in the reservoirs could flow by gravity to adjacent ponds.

- **Pond size**. Although some crawfish ponds contain hundreds of acres, small ponds with about 10 to 20 surface acres enhance production through better water circulation. Baffle levees also help force water through the pond's aquatic vegetation. Possibly more baffle levees in DMCAs would increase production in large ponds.

- **Dredge sediment**. Dredge sediments deposited in crawfish ponds should be analyzed for texture, fertility, and pollutants. Quantity, time, and location of dredge sediments applied to crawfish ponds are important, too. Soils with high content of clay are optimal for stabilizing crawfish burrows during the reproductive phases. Such textural class as sandy clay, sandy clay loam, clay loam, and siltly clay loam have sufficient clay content for crawfish culture (Coche 1985, as cited by de la Bretonne and Romaire 1989). Fertility of the dredge sediment should be sufficient to grow rice (*Oryza sativa*) or native aquatic plants, such as alligator weed (*Alternanthera philoxerides*), water primrose (*Ludwigia* spp.), and smartweed (*Polygonum* spp.).

  Accumulation of heavy metals and pesticides in crawfish are not at levels affecting man (Huner and Barr 1991); nevertheless, the DMCAs sediments should be monitored periodically for suspected contaminants. Many insecticides, herbicides, and fungicides are toxic to crawfish (Huner and Barr 1991). For example, synthetic pyrethroid insecticides (Aldrin and Ambush or Permethrin) at rates of only 0.001 lb/acre-ft of water will kill about half of the crawfish in only five days. Twenty-four additional insecticides, 11 herbicides, and five fungicides also have LC5O's ranging from 24 to 120 hr for crawfish.

- Deposition of dredge sediments on flooded crawfish ponds could adversely affect crawfish production in numerous ways, including:

  * Increased turbidity resulting in reduced photosynthesis and primary productivity in ponds.
  * Buried emergent aquatic plants and crawfish.
  * Decreased pond depths and exposure of crawfish to dessication and predation.
  * Increased chemical oxygen demand of the pond waters and stressed crawfish.

  Applied to drained crawfish ponds, dredge slurries could seal burrows or force the broodstock to suffer in hot, anaerobic waters.

- **Stocking schedule**. Fertile female crawfish are stocked in crawfish ponds. In Louisiana, the optimal stocking period is between April and May. If stocked prior to April, the percentage of fertile females is low. After May female crawfish are difficult to obtain because most female crawfish have burrowed.

  The windows to stock fertile female crawfish necessitates completion of DMCAs

prior to April in most Gulf and South Atlantic states. Hatchery production of juvenile red swamp crawfish was recently demonstrated (Trimble and Gaude 1988), and stocking schedules may be lengthed in the future if hatchery-reared juvenile crawfish become an economical option for stocking ponds.

- **Water quality**. Water quality in crawfish ponds especially concerns the concentration of dissolved oxygen for two reasons. First, aquatic plants in crawfish ponds consume large amounts of oxygen when they respire at night. Second, large quantities of dissolved oxygen are removed from pond water during the decomposition of pond detritus at initial flooding. Therefore, crawfish ponds require well-aerated water. A pumping capacity of about 100 gpm/acre is presently recommended for crawfish ponds (de la Bretonne and Romaire 1989); however, the pumping capacity for ponds greater than 30 acres and with high levels of organic matter may approach twice the recommended pumping rate to maintain dissolved oxygen above 2 ppm, the minimum for good production. Some commercial crawfish ponds are also aerated with paddlewheels, and the results look encouranging (R.P. Romaire, personal communication).

  Salinity affects survival and growth of red swamp crawfish. Newly hatched red swamp crawfish did not survive salinities of 10, 20, and 30 ppt, but crawfish 4 to 5 cm long grew better at 10-ppt salinity than 0 and 20 ppt under laboratory conditions (Loyacano 1968). Red swamp crawfish spawned and their eggs hatched in a production pond with salinities ranging from 4.4 to 7.9 ppt, and production of marketable crawfish was about 270 lb/acre (Perry and La Caze 1969). In another trial, production of red swamp crawfish and white river crawfish (*P. zonanqulus*, formerly called *P. acutus*) was approximately 260 lb/acre with salinities ranging from 0.8 to 1.5 ppt (Perry and Trimble 1990).

  Waters of DMCAs require additional water quality analyses for optimal crawfish culture. Approximately 100 mg/liter (range: 50-250 mg/liter) as total hardness and total alkalinity as is recommended (de la Bretonne et al. 1969). Ammonia and nitrite at 2 and 4 mg/liter of N, respectively, kill crawfish (Hymel 1985, as cited by de la Bretonne and Romaire 1989). The pH of freshwater crawfish ponds oscillates around 7 due to the buffering effect of the hard water; pHs in brackish ponds may be slightly higher.

- **Economics**. Louisiana's harvest of wild crawfish in the Atchafalaya Basin plays a very significant role in harvesting potentials for ponds. The wild crop not only comes in every year, but floods the market with crawfish every 2 to 3 years out of 5 years. When the wild crop comes in or even the speculation of it occurring is announced, the dock value for crawfish drops drastically toward the breakeven costs (approximately $0.35/lb) for harvesting the wild crop. Pond crops with breakeven prices exceeding costs for the wild crop shut down, and perhaps two-thirds of the pond production is usually unharvested at sites near the Atchafalaya Basin. Generally, ponds distant from the wild crop are profitably harvested if their harvesting and marketing expenses are less than the cost of transporting the harvested crop to the area.

Opportunities for production of red swamp crawfish in DMCAs

The two general benefits of DMCAs for aquaculture show promise specifically for production of red swamp crawfish. First, aquaculture sites along waterways are usually suitable for crawfish production. Pumping cost for surface waters are less than deep wells. Aeration and predator-control structures can optimize the inffluent, and adjacent waterways reduce lengths of ditches for effluent. Second, utilization of DMCAs reduces fixed costs for levees and water control structures. The soils

used for DMCAs are high in clay content and are ideal for crawfish culture.

Rotation of a crawfish crop with other aquaculture crops may have potential in DMCAs in the southern United States. For example, pond production periods for rearing crawfish (October through April) favorably match with the period (May through September) for growing out marine shrimp and freshwater prawns. Hatchery and pond production methodology is well documented for marine shrimp (Treece and Yates 1990, Villalon 1991) and freshwater prawns (Sandifer and Smith 1985). In crop rotation, juvenile crawfish would also be produced in hatcheries (Trimble and Gaude 1988) and fed formulated rations for growout in DMCAs. Production of 1,058 lb/acre of red swamp crawfish was obtained with formulated feed (Clark et al. 1974), and two commercially available crawfish feeds are currently available (Avault and Brunson 1990).

Freshwater Prawns

Worldwide, the aquaculture of freshwater prawns has focused on the Indo-Pacific's giant prawn, *Macrobrachium rosenbergii*. The prawn received considerable research and commercial investments from the late 1960s through the 1980s in the United States, and today it is cultured in Mississippi (10 acres), South Carolina (1 acre), and Texas (30 acres).

In the United States, production of *M.rosenbergii* requires three phases: hatchery; nursery; and growout (Sandifer and Smith 1985). The first two phases use heated facilities to headstart the prawns, so that growout can be completed in outdoor ponds before temperatures in the fall decrease growth (O °F) or cause mortalities (7 °F). The nursery phase also requires brackish water of about 12-16 ppt salinity, about one-half the salinity of natural seawater.

Additional water quality requirements of the prawn were reviewed by Sandifer and Smith (1985). Concentration of dissolved oxygen limits growth at about 3 ppm at 82 °F and at almost 5 ppm at 91 °F with larger prawns more susceptible to oxygen stress than smaller prawns. Growth rate of juvenile *M. rosenbergii* is affected by nitrite, nitrate, and ammonia necessitating flow through culture systems or low stocking densities. Total hardness above 300 ppm and total alkalinity above 180 ppm is not recommended for growout of juveniles. Straus et al. (1991) suggest that juvenile prawns should not be exposed to pHs greater than 9.5 or un-ionized ammonia greater than 2 ppm at pH 8.5.

In monoculture of the prawn, production in earthen ponds is about 980 lb/acre with about 80 percent of the prawns averaging about 25 count, heads-on (Smith et al. 1981). The effects of different stocking densities and average size on marketable crops of prawns was reviewed recently (D'Abramo et al. 1989). Polyculture of *M. rosenbergii* has been investigated with many other species, including golden shiners (Perry and Tarver 1987, Scott et al. 1988) and channel catfish (Huner et al. 1980, 1981, 1983; Miltner et al. 1983; D'Abramo et al. 1986; Heinen et al. 1987, 1989) in the United States.

Constrainsts for production of freshwater prawns in DMCAs

The major problems with growout of freshwater prawns in the United States include: climate; marketing; economics; salinity; and seed stock (Sandifer and Smith 1985). At DMCA sites, additional constraints may include pond size and dredge sediments.

- **Climate**. Ambient water temperatures in the United States limit pond production of *M. rosenberqii* to about half a year (May through September) when temperatures fall below 61 °F, the prawns become immobile and must be harvested individually from drained ponds. Temperatures 6 °F lower are fatal.
- **Marketing**. Pond-run prawns vary greatly in size from drained ponds, and approximately 20 percent of the crop is below acceptable market sizes.

- **Economics**. The ponds are used for only 5 to 6 months each year for fresh water prawn growout, and the return on investment is proportionally lowered.

- **Salinity**. Salinities above about 10 ppt are unsuitable for growout of *M. rosenberqii* (Ling and Costello 1979, Smith et al. 1982, as cited by Sandifer and Smith 1985).

- **Seed stock**. Postlarval freshwater prawns must be reared and maintained at separate brackish-water hatcheries. Few such facilities exist today in the United States, and the availability of the seed stock is somewhat questionable. Transportation of the seed stock also adds risk and expense.

- **Pond size**. As for crawfish ponds, 10 to 20 surface-acre ponds insure better water circulation than ponds with 40 to several hundred surface-acres.

- **Dredge sediments**. It is likely that the addition of some slurries would decrease concentrations of dissolved oxygen in freshwater prawn ponds.

Opportunities for production of freshwater prawns in DMCAs

The two general benefits of DMACs for production of red swamp crawfish also apply to freshwater prawns. The DMCAs would require interior levees capable of supporting vehicles for stocking, feeding, and sampling the crops. These levees would have slopes of about 3:1 and crowns at least 14 ft wide. The clay levees must be covered with about 4 in. of shell or slag to prevent vehicles from getting stuck or sliding off the wet, clay crowns. Interior levees of the DMCAs should enclose about 10 to 20 surface acres. The interior ponds would be rectangular if a water flow-through system is used, and the pond's water influent and effluent should be at opposite ends. On the other hand, square or round ponds may help circulate water if paddlewheels are used to aerate pond waters. For both systems, water should enter drainage ditches after flowing once through a pond, i.e. the ponds should not be built in series. Recirculation of pond waters in DMCAs would require water treatment to remove nitrogen compounds, including ammonia and nitrogen, which most likely would be the system's limiting factors for water quality.

Brine Shrimp

Brine shrimp (*Artemia* spp.) are small crustaceans used as food for aquarium fish and the hatchery production of many aquaculture crops, such as striped bass, red drum, walleye, marine shrimp, freshwater prawns, and lobsters. Initial supplies of brine shrimp came from California's Bay of San Francisco and Utah's Great Salt Lake in the 1950s. Demand from the expanding aquaculture and aquarium industries raised the wholesale price of brine shrimp cysts, which are dormant thick-shelled eggs, from less than $4.50/lb in the 1950s to over $45/lb in the 1970s. Today, brine shrimp are produced worldwide and range in price from $11/lb for brine shrimp with large larvae and low level of essential fatty acid 20:5(n-3) to $36/lb for brine shrimp with small larvae and high level of the essential fatty acid (Bengtson et al. 1991).

Commercial exploitation of numerous species and varieties of brine shrimp in their natural environments was recently described by Sorgeloos et al. (1986), Bengtson et al. (1991), and Lenz and Browne (1991); reportedly, principal natural habitats in the United States for brine shrimp, *Artemia franciscana*, include lakes and salterns in Arizona, California, Nebraska, New Mexico, Utah, and Washington with salinities ranging from 30 to 330 ppt (Lenz and Browne 1991). However, approximately 70 percent of the world's supply of brine shrimp comes from Utah's Great Salt Lake (Bengtson et al. 1991).

Production of brine shrimp in solar saltwork ponds located in dry, hot climates was also recently reviewed (Sorgeloos et al. 1986, Tackaert and Sorgeloos 1991). Water in the ponds evaporates, until elevated salinities (100-200 ppt) kill all predators of brine

shrimp. Brine shrimp nauplii are then added to the ponds where they grow and reproduce. When the salinity approaches 250 ppt, the brine shrimp produce cysts. Alternative ways to promote cyst production include: (1) stimulating algae densities to stress brine shrimp with pre-dawn low concentrations of dissolved oxygen; and (2) fluctuating salinities rapidly.

In addition to high salinities, nine additional management techniques are recommended for optimal production of brine shrimp in ponds (Tackaert and Sorgeloos 1991). First, minimal pond depth is maintained at 3 feet to avoid high water temperature lethal to brine shrimp. Second, soil and water pHs are buffered if necessary with calcium carbonate to pHs above 7. Third, organic and/or inorganic fertilizers are added to encourage microalgal blooms. Fourth, strain of brine shrimp stocked is carefully considered. Fifth, brine shrimp nauplii at the first instar stage are stocked at 10 to 20 nauplii/L. Sixth, green algae (*Tetraselmis* and *Dunaliella*) and diatoms (*Chaetoceros*, *Navicula*, and *Pleurosigma*) are encouraged and filamentous blue-green algae (*Lyngbya* and *Oscillatoria*) are controlled. Seventh, water quality is monitored for dissolved oxygen, pH, temperature, inorganic phosphate, nitrate, nitrite, ammonia, and turbidity. Eighth, samples are taken weekly to analyze population dynamics. Ninth, cysts and motile forms of brine shrimp are carefully harvested, prepared, and packaged. These pond management techniques result in about 10- to 20-kg dry weight cysts and 100- to 375-kg wet weight biomass of brine shrimp/hectare/month.

Constraints for production of brine shrimp in DMCAs

Constraints for production of brine shrimp in DMCAs include: precipitation; marketing; and economics.

- **Precipitation**. Rainfall averages from 20 to more than 60 in. for most of the United States on the Atlantic, Gulf of Mexico, and Pacific seacoasts. DMCAs in these areas may have insufficient evaporation rates to naturally elevate salinities to the 100- to 200-ppt range because of the area's precipitation rates.
- **Marketing**. Cysts and other brine shrimp products will probably be limited to markets in the United States. Commercial brine shrimp products were available in the 1980s from many countries (Argentina, Australia, Brazil, Colombia, People's Republic of China, France, and Thailand), and the industry should expand, especially in Southeast Asia and Central America (Bengtson et al. 1991).
- **Economics**. As for crawfish, production costs for rearing brine shrimp in DMCAs may exceed the expenses of collecting brine shrimp products from the Great Salt Lake and the Bay of San Francisco.

Opportunities for production of brine shrimp in DMCAs

The two general benefits of DMCAs for production of red swamp crawfish and freshwater prawns apply also to brine shrimp aquaculture. Generally, western portions of the United States, which have precipitation rates of 20 in. or less, show the greatest potential for brine shrimp culture. Nevertheless, other areas with salt deposits or saline aquifers near DMCAs may have unique opportunities. Brine shrimp were also cultured at a wastewater treatment facility in Texas (Milligan et al. 1980).

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Fee Fishing[1]

by
Billy Higginbotham[2]

Abstract

A fee fishing enterprise is both aquaculture and recreation. The operation must fully satisfy the biological requirements of the fish while meeting the market demands of the customers. The fee fishing operator must wear both hats to be truly successful.

The oral paper presented by Mr. Higginbotham was a composite of several recent papers under his authorship. They will help the would-be-entrepreneur evaluate whether potential DMCA sites might also be suitable for a fee fishing venture. The papers deal with the key parameters for successful fee fishing enterprises and include details on:

- *Site requirements for fee fishing.*
- *Design and construction.*
- *Equipments requirements for fee fishing.*
- *Species evaluation.*
- *Stocking and biological management.*
- *Defining the management components of fee fishing.*
- *Marketing guidelines in a successful fee fishing venture.*

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1 For further information on fee fishing, the following technical papers by Mr. Higginbotham should be consulted. Mr. Higginbotham works as a Texas Agriculture Extension Service Agent for Texas A&M University in Overton, TX, and may be contacted there.

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A Preliminary Evaluation of the Potential Use of Dredged Material Containment Areas as Nurseries for Wetland And Dune Vegetation

by
Pace Wilber[1]

Introduction

Each year, the U.S. Army Corps of Engineers (USACE) and other parties remove enough material (about 300 million cu yd) from navigation channels and harbors to cover the entire city of Washington, DC, to a depth of 5 ft (Hatch 1988). Although exact figures are unknown, at least half the material is placed in dredged material containment areas (DMCA). A typical DMCA is on private property and made available to USACE via an easement or other form of approval whereby USACE is allowed to place dredged material on the site for a specified number of years. The life-span of a DMCA can vary, however, most are designed to last 50 years. Even though 50 years is a long time, USACE still must acquire approximately 7,000 additional acres for DMCAs each year. This need and the increasing awareness that dredged material can be used for constructive purposes led to a major effort to describe potential beneficial uses of dredged material during the 1980s (U.S. Army Corps of Engineers 1986). These beneficial uses include: wetland creation; aquatic and upland habitat development; beach nourishment; landfill capping; and aquaculture (Figure 1).

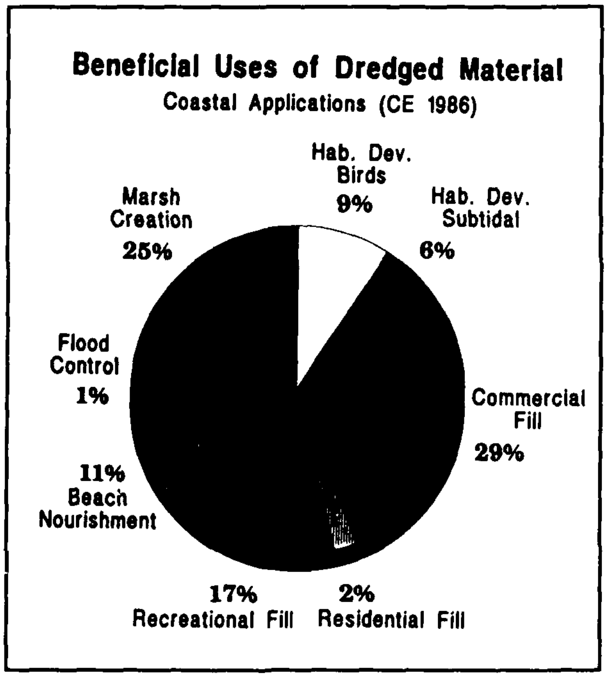

Figure 1. Relative frequency of the types of projects where dredged material is used for a constructive purpose (adapted from U.S. Army Corps of Engineers 1986)

A beneficial use that has yet to be investigated thoroughly is the potential (practical and economic) for DMCAs to be used as nurseries for wetland and dune vegetation. The common observation that wetland and dune plants often recruit onto DMCAs clearly demonstrates the biological feasibility of such a use (e.g., Kruczynski et al. 1978, Landin et al. 1989a). In addition, a major success of USACE's beneficial-use program has been the demonstration that wetland vegetation can be easily grown on dredged material (Landin et al. 1989b), further demonstrating that converting DMCAs into nurseries is biologically feasible. This paper will outline some of the technological, legal, and economic concerns of creating plant nurseries on two types of DMCAs: upland DMCAs in freshwater environments; and open-water DMCAs in tidal, coastal environments (which are often called containment islands). Guidelines on which species to grow and how to plant and care for them

[1] U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

have been reviewed by several authors (e.g., Broome et al. 1982; Lewis 1982; Knutson and Woodhouse 1983; Craig 1984; U.S. Army Corps of Engineers 1986; Kusler and Kentula 1989) and will not be reviewed here except to say that such guidelines vary geographically (e.g., McKee and Patrick 1988). Finally, it should be noted that the concept of planting DMCAs is not limited to wetland and dune species. USACE's Vicksburg District has modified the hydrologic regime of an existing DMCA to make the site suitable for farming particular plant species.

Technological Feasibility

In order to discuss how a DMCA might be modified to accommodate a plant nursery, a brief description of typical DMCA management is needed. In addition, it will be necessary to discuss upland DMCAs separately from tidal DMCAs.

Upland DMCAs

The features of DMCA operation relevant to this discussion have been reviewed by Haliburton (1978) and Palermo et al. (1978). Most upland DMCAs consist of dikes, an inflow pipe, and an adjustable outflow pipe (Figure 2). Dredged material is pumped to the site in the form of a high-water-content slurry (85 percent). When the slurry enters the DMCA, coarse material falls out of the stream relatively fast and accumulates near the inflow pipe. Finer material that remains suspended in the stream may require several minutes to hours to settle from the water that accumulates within the DMCA. By adjusting the depth of the water (often called the pond depth), and hence the flow out of the DMCA, the amount of particulate material leaving the DMCA and distribution of fine material within the DMCA can be controlled. After settlement, the slope of the fine material between the inflow and outflow pipes is approximately 1:500 (vertical:horizontal). Because motions that accompany dredging material from a channel bottom and pumping it a mile or more in a slurry are quite violent, most fine particles that were aggregated into clumps are broken into smaller particles. Therefore, the coarse material in the DMCA is almost always sand, and the fine material is almost always silts and clays.

After pumping into the DMCA has stopped, the outflow pipe is adjusted so water can drain from the dredged material. Draining the material (often called dewatering) serves several purposes:

- It allows a crust to form on the surface of the material so workers and equipment can move onto the site.
- It decreases the volume of the interstitial (sediment pore) spaces which decreases the volume required to store a given weight of dredged material.
- It may be necessary for mosquito control.

Trenches, especially near the outflow pipe, are often used to increase drainage of the dredged material and to prevent rainwater from accumulating in the DMCA. Small, stagnant-water pools that occur in DMCAs result from uneven settling of material before and after pumping and from other factors (e.g., wind and vegetation) that alter microtopography.

The general changes needed to transform an upland DMCA into a wetland plant nursery are clear. Rather than allowing the site to thoroughly drain after disposal, the outflow pipe should be adjusted to maintain water in the DMCA at a level conducive to the target plant species. In many areas and under normal climatological conditions, such water levels can be maintained without pumps or other forms of irrigation because the rate at which water leaches from the bottom of DMCAs is low (about 3-cm unit-area/year). However, at least several additional considerations are apparent.

First, one must decide whether or not to dewater the site after disposal. If fine-grained dredged material is not dewatered, it will not compact sufficiently to support equipment or workers for many years, which will make maintaining a nursery very difficult. (After

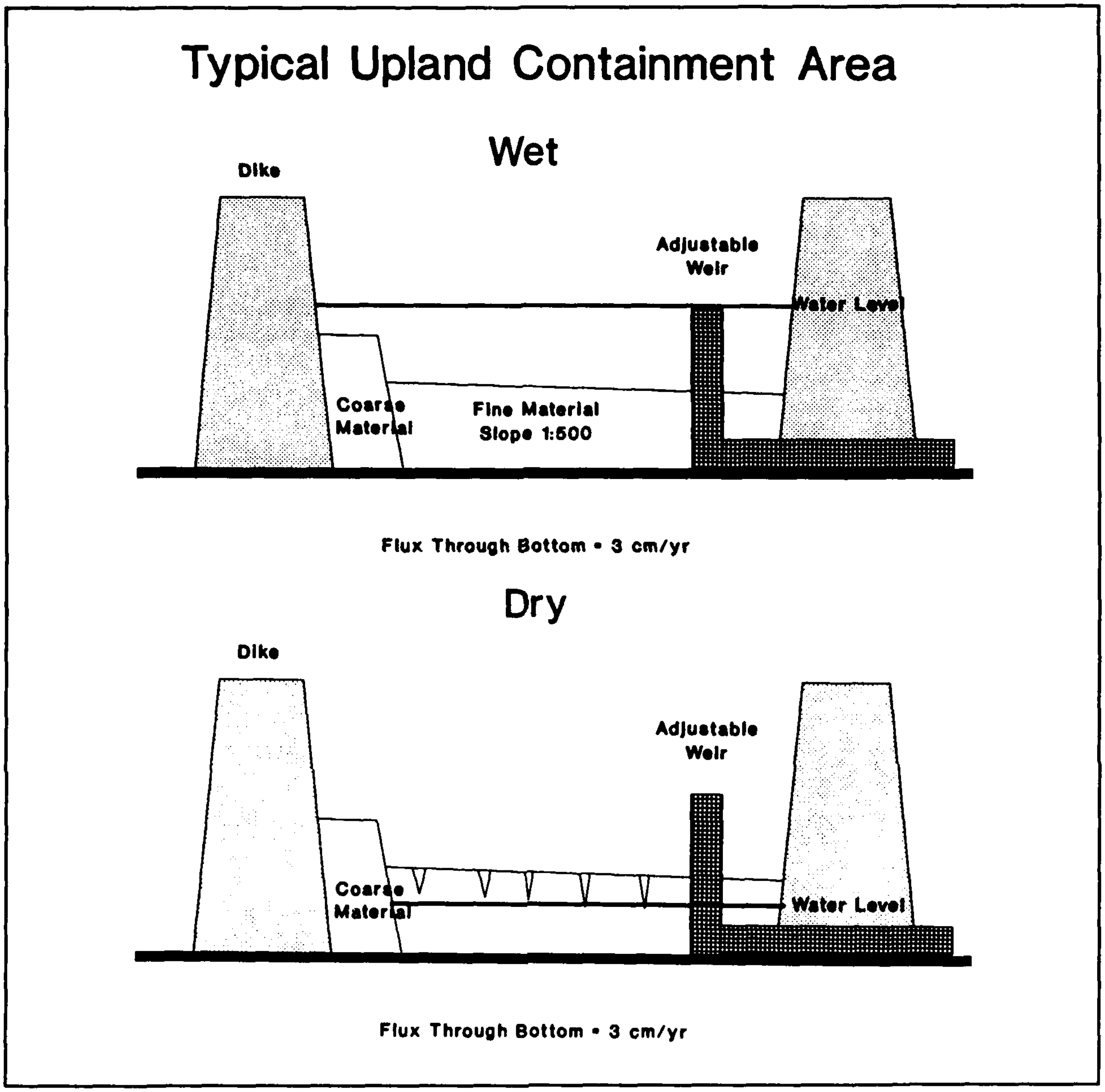

Figure 2. Typical operation of upland DMCAs. Input pipes, which have been omitted for clarity, would be near the coarse material

dewatering has formed a crust on the sediment surface, the crust will remain relatively stable when the DMCA is refilled with water.) In addition, if a DMCA is not dewatered, interstitial spaces will not be minimized and, hence, the long-term capacity of the site will be reduced. Both of these observations strongly suggest DMCAs should be dewatered before transformation into a nursery. There are at least two consequences of dewatering the site:

- The DMCA cannot be used as a nursery for at least 3-6 months after dredging (the minimum time required for a crust to form on the surface).
- Some effort must be spent to rehydrate the site. The biological effects (positive and negative) of dewatering and then rehydrating dredged material before planting have not been examined.

Second, one must decide which plant species will be grown in the DMCA. The moisture requirements of wetland plants vary considerably. Although a single DMCA can include several moisture levels, there probably is a limit as to how many levels can be maintained, which will limit the types of plants that can be grown. It may be difficult to maintain water levels that inundate coarse material that accumulated near the inflow pipe. Because water percolates through coarse material much faster than fine material and the coarse material near the pipe probably will not be capped by finer material, the coarse material near the inflow pipe may function like a drain. Thus, if nothing is done to prevent water from leaching through the coarse-sediment plug or to replace water that passes through the plug, the area available for wetland plants will be limited to the fine-sediment portion of the DMCA (Figure 3). Because this area has a shallow slope, only a few hydrologic regimes are possible unless one regrades material within the DMCA and/or actively irrigates portions of

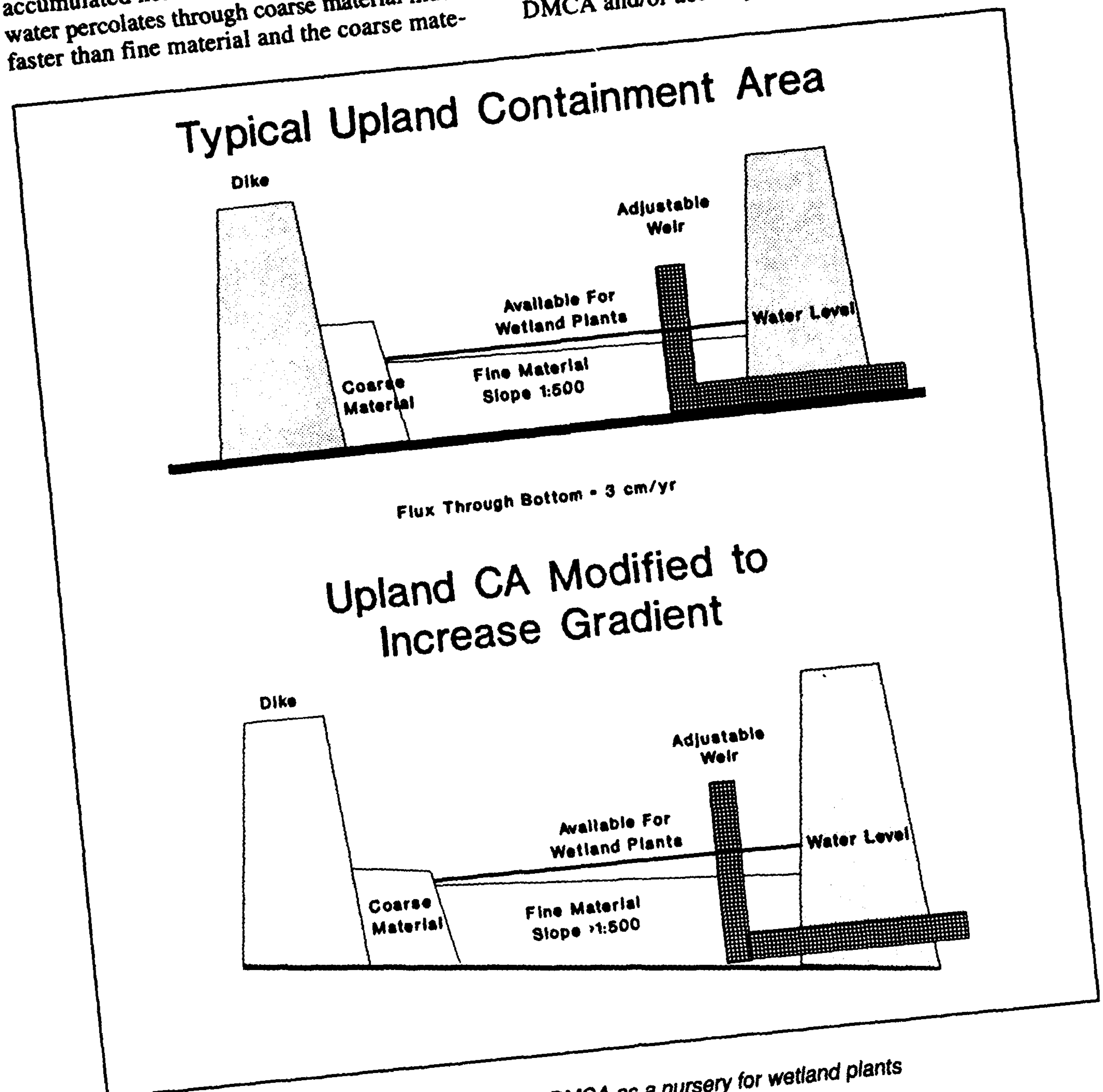

Figure 3. Operation of a DMCA as a nursery for wetland plants

the DMCA. This problem may be at least partially alleviated by constructing the DMCA with a sloped bottom (Figure 3). The resulting slope of the dredged material will be between 1:500 and the bottom slope, potentially increasing the hydrologic gradients present. However, this slope will approach 1:500 as the DMCA is used for subsequent disposal events. Multi-celled DMCAs may be another way to increase the range of potential hydrologic gradients. One cell could be used for plants that require damp soils; another for inundated soils. Choice of plant species is also important because a species' biology will affect the number of marketable crops that can be raised between disposal events.

Third, the consequences of fertilizing the dredged material need to be investigated. During USACE's beneficial-use program, several experimental wetlands were created that included examinations of the effects of fertilizers on the establishment of wetland vegetation. Although most studies concluded that fertilizers do not enhance establishment of wetland vegetation (e.g., Kruczynski et al. 1978, Webb and Dodd 1989), use of fertilizers should not be discounted. The goal of a nursery is to produce seeds or transplantable plant material, which is different than trying to create a permanent wetland. Nutrient levels can affect the development of belowground biomass (roots and rhizomes) of many plants, and below ground biomass condition affects transplantability. Effects of nutrients on seed production are also well documented. Thus, although it seems clear that fertilizers are not necessary to establish wetland plants on dredged material, fertilizers may improve operation of a nursery by increasing seed production or the ease at which transplantable material can be harvested. The amount of fertilizers needed to improve these parameters is likely to be small since fine-grained dredged material often includes a high proportion of organic material.

Tidal DMCAs

Tidal DMCAs are usually constructed in open-water (Figure 4) with an outflow pipe that empties below mean low water (MLW). Because the outlet is below MLW, seawater can travel in both directions through the pipe until water levels within the DMCA equal those outside the site. Thus, assuming the cumulative cross-sectional areas of the outflow pipes are not limiting, a natural tidal regime can be established within a DMCA. Such a regime will be necessary for some wetland species (e.g., *Spartina alterniflora* or smooth cordgrass) and less critical for others (e.g., *Juncus roemerianus* or black needle rush).

Elevations, relative to MLW or some other datum, of the planting areas within tidal DMCAs will be critical, especially in areas with small tidal ranges. Most coastal plants have specific microhabitat requirements (Eh, pH, nutrient levels, etc.) that generally correlate with MLW elevations. Thus, ensuring that planting elevations within a DMCA reflect the natural elevations of the target species will help ensure that adequate microhabitat is provided. In areas with small tidal ranges, there is less room for error in creating optimum elevations. The need to control elevations within the DMCA has an important consequence for the long-term use of the site as a nursery for salt-tolerant species. The DMCA will eventually contain enough dredged material that passive establishment of a natural tidal regime will not be possible (i.e., the top of the dredged material will be above ambient sea level). When this happens, either water will have to be actively pumped into the site or non-salt-tolerant species grown in order to sustain the nursery. The converse of this problem may be present during initial operation of the DMCA: elevations may be too low for wetland species. A potential solution to these problems would be inclusion of intertidal shelves along the dikes (Figure 4). It also may be possible to grow seagrass in a DMCA if the site is constantly inundated.

Dune Vegetation and Coastal DMCAs

Dune rejuvenation and stabilization programs are becoming more common in the southeastern United States, partly for aesthetic

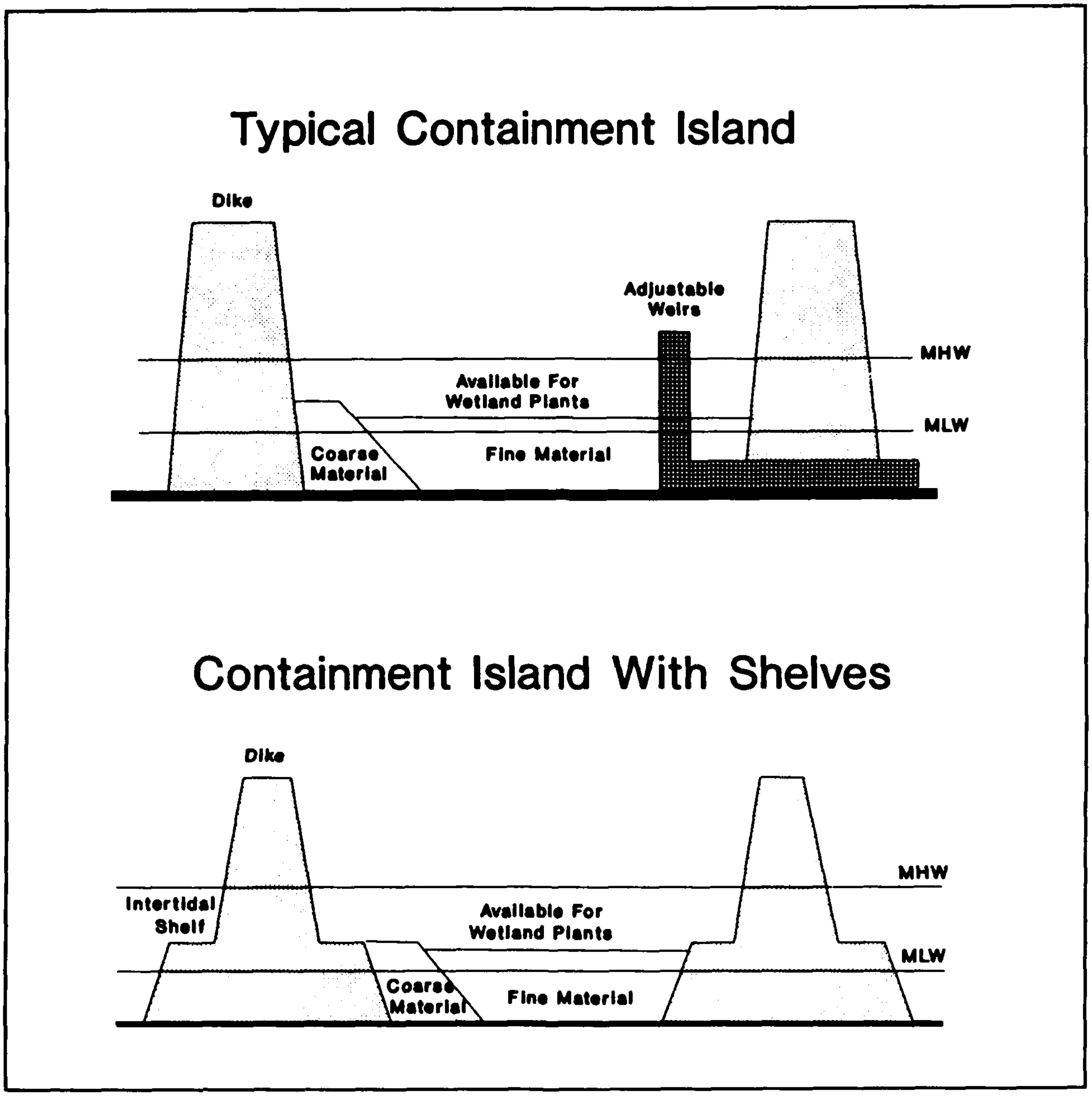

Figure 4. Typical operation of a tidal DMCA and how a tidal DMCA may be modified to accommodate wetland plants. Inflow and, in the latter case, outflow pipes have been omitted for clarity

reasons and partly because of an increasing awareness that a robust dune system is an essential part of a stable beach environment. Since dunes are essentially piles of sand, they can be moved, destroyed and created over time by winds and overwash. Vegetation greatly slows migration and destruction of coastal dunes and accelerates their creation by holding sand grains together, decreasing wind and water shear stresses, and trapping sand grains. For this reason, vegetation (especially dune grasses) is often used as a management tool to stabilize upland dikes of coastal DMCAs. Using DMCAs as a nursery for dune vegetation would simply take this management tool one step further to harvesting plants or seeds for establishment elsewhere.

Using DMCAs as nurseries for dune vegetation is likely to be more difficult than using them as nurseries for wetland species. With the exception of *Ammophila breviligulata*

(American beachgrass), which occurs in North Carolina and northward, transplanting most dune plants is difficult because of their extensive root systems, which are necessary for absorbing sufficient water and nutrients from a sandy soil. In addition, sandy soils promote extensive root systems by offering relatively low physical resistance to root growth. The sandy portions of a DMCA (including dikes) are likely to cause similar responses in plants grown on them. A potential solution to this problem is to water and fertilize the plants frequently, but this will increase the costs of operating the nursery.

Legal Feasibility

Many of the legal considerations regarding use of a DMCA as a nursery are similar to those regarding use of a DMCA as an aquaculture facility. Briefly, these concerns include: establishing a clear procedure that allows both the DMCA operator and USACE to use the site for their respective purposes with minimal interference from each other; and establishing who is responsible for any structural failures or erroneous placement of contaminated material in the site. However, there is at least one unique concern when converting a DMCA into a wetland or dune plant nursery. Many local, state, and Federal agencies use wetland and dune plants to define the geographic areas over which their regulatory programs have jurisdiction. If a DMCA nursery is successful, the nursery may come under the jurisdiction of these programs and potentially require dredge-and-fill permits or other forms of approval for recontouring the dredged material or harvesting plants. In addition, the discharges from these facilities, especially if fertilizers are used, may be considered potential pollution sources that require regulation. The significance of these concerns and their potential solutions will vary on a geographic and, perhaps, a case-by-case basis.

Economic Feasibility

Several wetland and dune plant species are already commercially available (Table 1). Demand for these plants comes primarily from mitigation projects stipulated by dredge-and-fill permits and from habitat restoration projects. Such projects often require very large numbers of plants. For example, planting on 3-ft centers requires almost 5,000 plants/acre, and over a thousand acres may be planted per year in some states (Florida DER 1991). However, it is not clear if current demands exceed supplies on regional scales. Another factor that requires additional study is the ramifications of different times between disposal events

Table 1A
Native Wetland Plants of the Southeast That Are Sold Commercially

Scientific Name	Common Name	Salinity Regime[1]
Aster carolinus	Climbing Aster	F to S
Avicennia germinans	Black Mangrove	S
Borrichia arborescens	Tree Oxeye Daisy	B to S
Borrichia frutescens	Sea Oxeye Daisy	B to S
Canna flaccida	Golden Canna	F
Crinum americanum	Swamp Lily	F
Distichlis spicata	Saltgrass	B to S
Hymenocallis sp.	Spider Lily	F to B
Iris hexogena	Angelpod Blue Flag	F
Juncus effusus	Soft Rush	F
Laguncularia racemosa	White Mangrove	S
Pontederia cordata	Leaf Pickerelweed	F to B
Rhizophora mangle	Red Mangrove	S
Sagittaria latifolia	Common Arrowhead	F
Saururus cernuus	Lizard's Tail	F
Sesuvium portulacastrum	Sea Purselane	B to S
Spartina alterniflora	Smooth Cordgrass	B to S
Spartina bakeri	Sand Cordgrass	F to S
Spartina patens	Saltmeadow Cordgrass	B to S

[1] F = freshwater species, B = brackishwater species, S = saltwater species. Mostly based on Beever (1986).

Table 1B
Native Dune Plants of the Southeast That Are Sold Commercially

Scientific Name	Common Name	Salinity Regime[1]
Ammophila breviligulata	American Beachgrass	F
Coccoloba uvifera	Seagrape	F
Conocarpus erectus	Buttonwood	B
Cynodon dactylon	Common Bermuda Grass	B
Distichlis spicata	Saltgrass	B
Ilex vomitoria	Yaupon Holly	B
Panicum amarum	Bitter Panicum	F
Prunus angustifolia	Chickasaw Plum	B
Quercus virginica	Sand Live Oak	B
Sabal palmetto	Cabbage Palm	B
Sesuvium portulacastrum	Sea Purselane	B
Spartina patens	Saltmeadow Cordgrass	F
Stenotaphrum secundatum	St. Augustine Grass	B
Uniola paniculata	Sea Oats	F

[1] F = foredune species, B = backdune species. Based on Broome et al. (1982) and Craig (1984).

on plant species and product selection. Besides relative demand and disposal frequency, economic factors that will affect successful operation of a DMCA nursery are likely to be similar to those that affect habitat creation as an alternative to other forms of dredged material disposal. The most important of these factors are the accessibility of the site and amount of post-disposal earthwork required to create appropriate elevations.

Acknowledgements

Conversations with Paul Schroeder (USACE), John Sanders (USACE), Steve Beamon (Ecoshores, Inc.), David Carpenter (Tampa Port Authority), Pam Reeder (Coastal Revegetation, Inc.), and Ann Redmond (Florida Department of Environmental Regulation) provided much of the material presented in this paper. However, I am responsible for any misrepresentations or errors.

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE December 1993

3. REPORT TYPE AND DATES COVERED Final report

4. TITLE AND SUBTITLE
Proceedings of the National Workshop on Containment Area Aquaculture; 11-15 November 1991, South Padre Island, Texas

5. FUNDING NUMBERS

6. AUTHOR(S)
Environmental Laboratory

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station, Environmental Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers, Washington, DC 20314-1000;
U.S. Army Engineer Waterways Experiment Station, Environmental Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Technical Report EL-93-26

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

High land and construction costs hinder development of pond-based aquaculture in the United States. A partnership with navigation interests may reduce these constraints. The dredged material containment areas (DMCAs) operated by the U.S. Army Corps of Engineers are structurally similar to aquaculture ponds and typically are used only once every 3 to 10 years. With the Corps and navigational interests contributing to dike construction and land acquisition, the costs of aquaculture may be reduced while providing the Corps with the additional disposal areas needed to maintain our nation's waterways. The feasibility of DMCA aquaculture was examined under the Containment Area Aquaculture Program (CAAP), which was sponsored by the Operations, Construction, and Readiness Division, Directorate of Civil Works, Headquarters, US Army Corps of Engineers, in cooperation with the Construction-Operations Division of the U.S. Army Engineers Galveston District.

The feasibility of DMCA aquaculture was demonstrated in 42 and 47 ha DMCAs near Brownsville, TX. Pumps, filters, and drainage structures were added to these DMCAs to accommodate aquaculture operations

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14. SUBJECT TERMS

15. NUMBER OF PAGES 188

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

13. (Concluded).

and a 1.6-ha nursery pond was constructed. During a 3-year period, four crops of penaeid shrimp were raised. Production rates averaged 670 kg/ha of whole shrimp (range: 338 to 1143 kg/ha) with 51-percent survival (range: 23 to 74 percent). Total production for the four crops was 116,088 kg of whole shrimp (71,878 kg tails) and was sold for over $475,000. Publications reviewing the demonstration project from engineering, economic, legal, and environmental perspectives have been prepared.

The culmination of CAAP was the National Workshop on Containment Area Aquaculture, which was held 11-15 November 1991 and provided an opportunity for experts in navigation, dredging, economics, and aquaculture to meet and discuss the lessons learned from CAAP and to suggest reasonable extensions of the information gained. Six general areas were discussed: aquaculture economics, aquaculture financing, site selection and planning, facility engineering, CAAP operations, and candidate species. The overall conclusions of the workshop was joint DMCA/aquaculture facilities are feasible for several species, and such facilities may enjoy economic advantages over traditional aquaculture operations. Project-specific information would be needed to quantify these advantages.